Saprolite slope design at the Rosebel Gold Mine

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The Rosebel Gold Mine, located in Suriname, is comprised of eight open pits which have been developed to varying depths. Due to their origin and tropical climate setting, the rocks throughout the site are deeply weathered with saprolite and transition (sap-rock) extending to depths greater than 70 m. Existing interim saprolite and transition slopes have been excavated in several of the operating pits. The performance of these slopes is extremely variable due to the impact of relict structures, groundwater, intense rainfall, and protolith.

A detailed geotechnical investigation program was undertaken during 2013 through 2014 to provide slope design configurations that could be practically implemented in this high-rainfall tropical environment using the capabilities of the equipment on site. This paper documents the methodology used to generate the saprolite and transition slope designs and the implementation requirements.

The slope design approach involved a detailed review of existing pit slope failures in various geotechnical settings along with findings from the geotechnical drilling program, to aid in the estimation of strength parameters of the materials and analysis of controlling factors on slope stability. A series of simple numerical models were then generated to support the slope designs. One of the controlling factors was found to be orientation of relict structures and foliation. Groundwater control was highlighted as another controlling factor. Back-analysis indicated that the most critical period from a groundwater perspective was when the mine floor was located at the base of the saprolites. This is due to elevated pore pressure in the toe of the saprolite slopes. As mining progresses into the more permeable transition material, passive drainage of the transition layer acts as a natural drain beneath the saprolites. Identification of this process enabled mine plans to be modified such that the natural drainage could be used to depressurize the slopes. Adjusting mine plans to take advantage of these natural processes reduced the need for a more complex and costly dewatering system.

Introduction

The Rosebel Gold Mine (RGM) is located approximately 85 km south of Paramaribo, the capital city of Suriname. The RGM site lies near the centre of the Guiana Shield, which extends from Venezuela in the west to the Amazon delta in the east. There are eight orogenic gold deposits on the RGM property; typically four or five of which are being mined at one time. Mining is done through conventional truck and shovel methods. Mining began in 2006 and since then eight pits have been developed to varying depths. Final depths for the proposed pits vary from around 200 to 350 m.

The hot, humid climate and intense rainfall within the region has resulted in a significantly deep weathering profile and the generation of residual soils. In some areas saprolite and sap-rock can extend to greater than 70 m depth. This paper documents the methodology used to design and implement pit slopes excavated in saprolite and transition (sap-rock).

Up until the end of 2011 only scoping level geotechnical work had been undertaken at the site. As pits became deeper an increasing number of geotechnical issues relating to saprolite instabilities impacted production. From 2012 to 2014, RGM geotechnical staff worked with SRK to undertake a full geotechnical site investigation programme to provide operational slope designs and implementation procedures for each pit. The geotechnical investigation work involved oriented core drilling with geotechnical logging, laboratory testing, and detailed pit mapping, including the use of photogrammetry and laser scanning.

Operational and geotechnical challenges

The main challenges faced by the RGM operation relating to saprolite and transition slope stability are summarized in Table I. An example of one of these challenges is shown in Figure 1, where a fault structure lowers the weathering profile locally causing fresh rock to sit adjacent to saprolite and transition along the same pit face. Identifying and addressing these challenges has been critical when designing slopes; *i.e.* the designs must be practical to implement and manage given the conditions and capabilities on site.

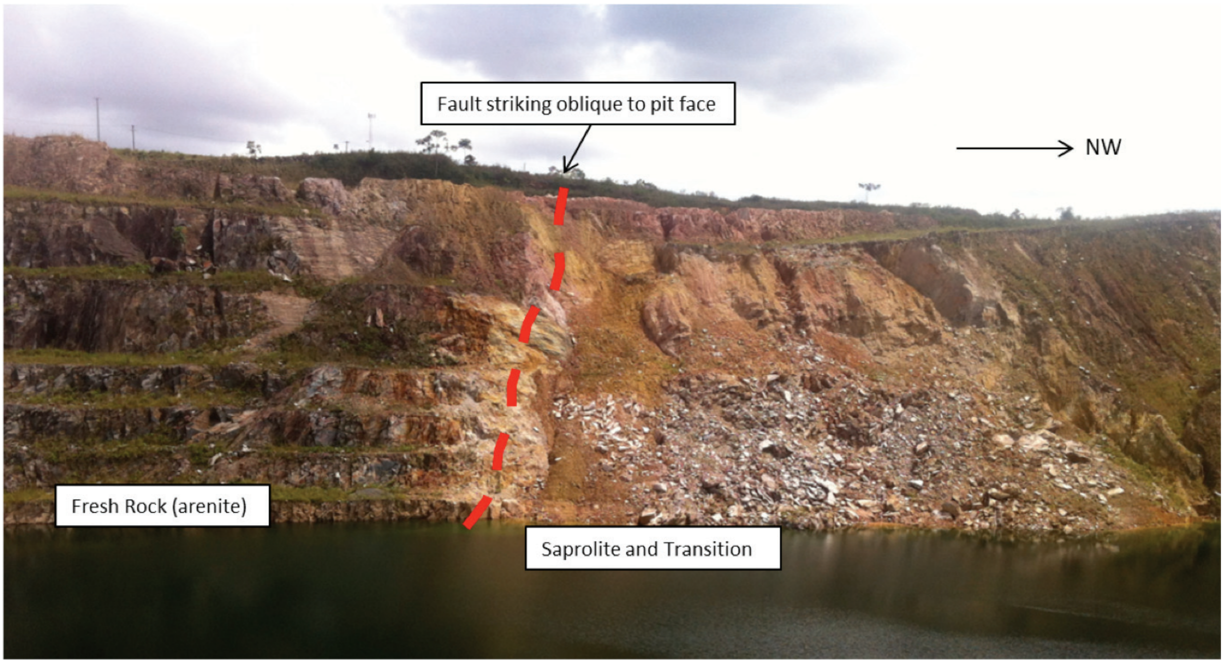

Figure 1 – Sharp contrast between fresh rock and transition due to a large fault striking oblique to the face

Table I. The geotechnical and operational challenges faced at Rosebel Mine

Challenge	Comments
Variation in existing saprolite slope performance	Each pit at RGM has different geology, structure, rock mass, and ground and surface water behaviour. Consequently the slope failure mechanisms are highly variable.
Staffing for multiple operating pits	One of the main challenges the Rosebel Engineering team face is managing geotechnical and hydrogeological issues across numerous pits at the same time. Implementing complex depressurization and dewatering systems for example is not practical or cost-effective within such an operation.
High rainfall and surface infiltration	Frequent high rainfall events cause water to feed slopes, increasing likelihood of failure. Water also exacerbates erosion and causes trafficability issues within the pit.
Variation in pore pressures	Pore pressures within saprolite slopes show significant variations both spatially and with time due to seasonal rainfall patterns and varying rates of mine advance
Sharp weathering contrasts exist along a pit face (Figure 1)	Faults often cause localised depressions in the weathering profile by acting as zones of increased permeability. The result is a sharp, localised drop in weathering profile along a pit face which must be mined at a lower inter-ramp angle than surrounding rock and in turn impacts stripping ratio if an over-conservative design approach is used.

Rosebel geology

The Rosebel Gold Mine lies within the Proterozoic greenstone belt of the Transamazonian Orogen, which stretches from the Amazon River in Brazil to the Orinoco River in Venezuela within the Guiana Shield. The belt is comprised of various volcano-sedimentary rocks including oceanic tholeiites, calc-alkaline felsic and mafic suites, greywackes, and pelites, all of which are deposited in a back-arc setting of a subduction zone and intruded by various magmatic bodies between *ca*. 2188 and *ca*. 2120 Ma (Veenstra, 1983; Gibbs, 1987; Marot *et al*., 1984; Gibbs and Barron, 1993; Vanderhaeghe *et al*., 1998). In the Rosebel Gold Mine area, these greenstone-belt-forming rocks are divided into three supracrustal rock types including, from the bottom upwards, the Rosebel district felsic to mafic volcanic rocks, turbiditic sediments, arenitic sediments, hosting felsic intrusions, and late diabase dykes, the latter of which are Permo-Triassic in age (Daoust *et al*., 2011). Economic gold mineralization has been recognized in sedimentary and volcanic rocks, while the intrusions show only rare gold occurrences and the dykes are totally devoid of any mineralization. The pits at Rosebel are primarily excavated in either the sedimentary or volcanic rocks. Consequently, the saprolite and transition protoliths are primarily volcanic rocks (andesites, basalts, and dolerites), and sedimentary rocks (arenites and turbidites).

Climate

The project area is subject to an equatorial climate. It is hot and humid and generally can receive rainfall at any time throughout the year, though seasonal variation does occur. The climate of Suriname is characterized by two short and two long wet and dry seasons. The short wet season is from December to January followed by the short dry season from February to April. The long wet season is considered to be from April to August and the long dry season between August and November.

A meteorological station is located at the main camp, and precipitation is also monitored at multiple pits. Average annual precipitation in the project area is estimated at 2284 mm. Potential evaporation is estimated to be around 1300 mm, and average surface runoff at the site is 770 mm. Potential recharge is assumed to be about 550 mm, some of which would manifest itself at surface water bodies as interflow and surface runoff. Approximately 50% of the rainfall occurs during April to August. During the dry season, evapotranspiration can exceed rainfall.

Weathering classification for rock mass domains

In general, the degree of weathering decreases with depth, resulting in different tropical soil horizons. While the ‘contacts’ between horizons are typically gradational, it is necessary to differentiate them for slope design as they form different rock mass domains used for pit slope design. Nomenclature and classification for different residual soils can differ in the literature. At Rosebel the residual soils have been classified purely on field strength alone using the ISRM classification (ISRM, 1981). Although quite simple, this has proved very effective and could be consistently employed by geological logging staff on site. Descriptions given to the rock mass domains differentiated by weathering are as follows (from shallowest to deepest):

- **Saprolite:** field strength of up to and including S5 (<0.5 MPa). It is highly weathered and behaves as a ‘soil’ in engineering terms, but may exhibit textural and structural features of the parent rock mass
- **Transition:** classified by field strength of S6 to R1 (0.5–5.0 MPa). This represents the ‘transition zone’ (often referred to in the literature as sap-rock) where material changes from soil behaviour to rock behaviour. Relict rock discontinuities strongly impact stability in this zone
- **Weathered rock:** classified by field strength of R1 to R2 (5–25 MPa) and exhibits oxidation through the rock or has oxidized joint surfaces. It typically has a higher fracture frequency than the underlying fresh rock where increased weathering has opened up incipient foliations or closed joints.
- **Fresh rock:** classified by field strength of R2 (>25 MPa) and above, and exhibits no or only slight weathering. Fresh rock generally has little discolouration, but may show localized iron staining along discontinuities where water flow is observed.

This paper focuses on the saprolite and transition (sap-rock) slope design.

Geotechnical characteristics

The saprolite colour is extremely variable from orange-brown to purple, on a very local scale. In the centre of the pits the saprolite is hydrothermally altered and typically more grey in colour, and contains the mineralization. Grab samples from test pits and drilled core were obtained from around final pit perimeters to investigate plasticity and grading. Irrespective of protolith, the saprolites were generally found to be low to medium plasticity silts with a trace of clay content. In terms of the Unified Classification system, the saprolites could be classified as ML or occasionally MH. Grab samples in the transition zone were also low plasticity and often had a high sand content.

Shelby tube saprolite samples were obtained from several pits at shallow depths for consolidation and triaxial testing. Multi-stage consolidated-undrained triaxial testing was undertaken with measurements of pore pressure to estimate shear strength parameters. Results of the testing gave friction angles from 24–28° and cohesion around 20–40 kPa. Shelby tube samples of transition material could not be obtained due to increased cementation with depth causing refusal during sampling. This indicated the strong variation expected in the cohesion values as a function of depth. Back-analysis of existing slope failures was used to further estimate the cohesion values (discussed below).

Shear strengths of the relict structures and parent fabric were found to be very difficult to test due to sampling issues. Some shear box testing was done on discontinuities in the more competent (deeper) transition core where the discontinuity was well preserved. Friction angles obtained were in the range of 18-22°.

Slope design methodology

The geomechanical behavior of saprolites is known to be extremely complex. Fully understanding the behaviour of the material and any variability across the site would be extremely costly and time-consuming. Given the large amount of current exposure from pre-mined slopes, it was felt that an empirical slope design approach could be taken. This involved a detailed review of existing saprolite and transition slopes to estimate strength parameters and failure modes, backed up with data from laboratory testing, oriented core drilling data, and pit mapping. Simple numerical modelling could be undertaken to investigate the impact of pore-water pressures on slope angles and stack heights. The approach used is illustrated in Figure 2.

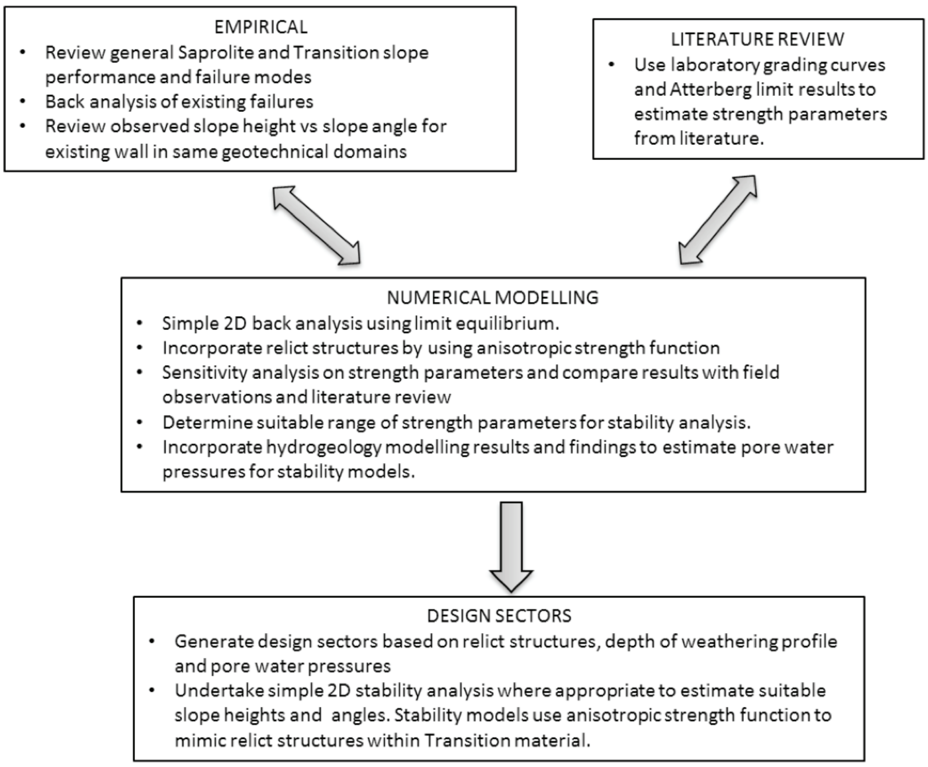

Figure 2 – Saprolite slope design methodology

Existing slope performance and failure mechanisms

A variety of existing saprolite and transition slope failures have occurred in the interim walls of the different pits at RGM. Understanding the mechanisms and cause(s) of failure was critical in design and implementation of final slopes. The different failure types observed are discussed below.

Gullying and erosion

Erosion, gullying, and piping, resulting from surface water infiltration and runoff are commonly observed, to different degrees, in all pits (Figure 3). The steep gullies observed indicate the high silt content present in the saprolites. When dry, these gullies can remain very steep, but on wetting, collapse of the soil structure occurs. Collapse typically results from loss or reduction of bonding between particles due to the presence of water (Fookes *et al*., 1997).

Erosion and piping on a bench scale is generally not too problematic; however, if allowed to persist to multiple benches then collapse of the gully could occur, washing out significant material into the pit. If piping and erosion were occurring behind a ramp then stability of the ramp might be compromised.

Figure 3 – Gullying and erosion on the eastern wall of Royal Hill Pit leading to washout of material over benches below

Creep and flow

Creep- and flow-type failures are seen to occur in the more weathered saprolites when they become highly saturated (Figure 4). Saturation is often due to a combination of surface water feeding the slopes, high infiltration, or poor drainage at the slope toe. An appropriate analogy is made by Booth and Hamman (2007), who compare the saprolite behaviour to that of a sponge. The weight of water in the material becomes a considerable part of the overall slope weight and thus the driving force. Rates of failures on a multi-bench scale are generally relatively slow (days to weeks) but can still be problematic when impacting mining or infrastructure.

Degree of saturation of the saprolites strongly impacts performance. Benches cut in partially dry saprolite will stand vertically at heights of up to 10m, however when fully saturated the material will readily collapse and flow.

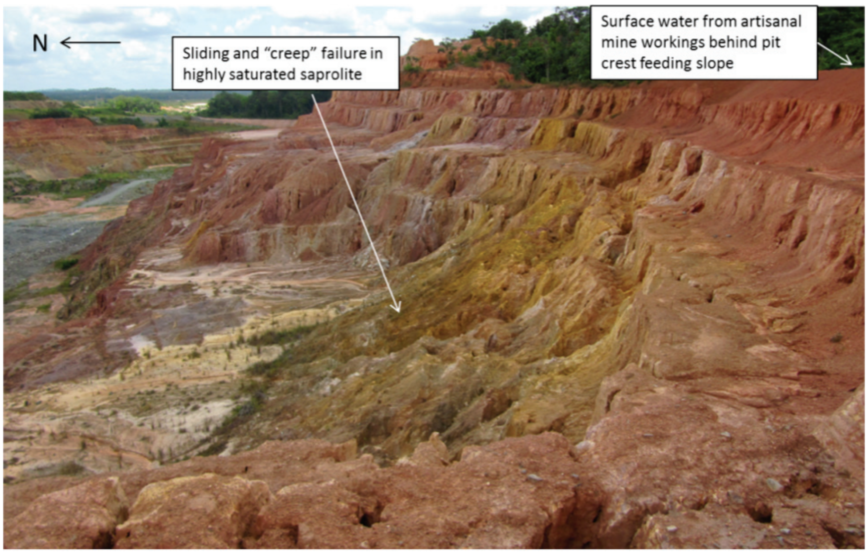

Figure 4 – Example of a creep style failure in highly saturated saprolites along the south wall of Royal Hill, south pit

Impact of relict structures

The presence of relict structures and the fabric of the parent rock have contributed to several slope failures, particularly in transition material. While the true mechanism may be very complex; the relict structures are seen to play a significant role. On 2 February 2010 a toppling-style failure occurred in the transition material along the southern wall of Royal Hill South Pit (Figure 5). Failure was caused by the presence of a subvertical relic foliation striking approximately parallel to the face. A steep structure striking oblique to the face provided a release surface on the left hand side of the failure. The failed material was likely above the water table; but failure may have been exacerbated by rainfall entering the subvertical foliation and creating positive pore-water pressures in the slope. Similar failures have since occurred along the same wall.

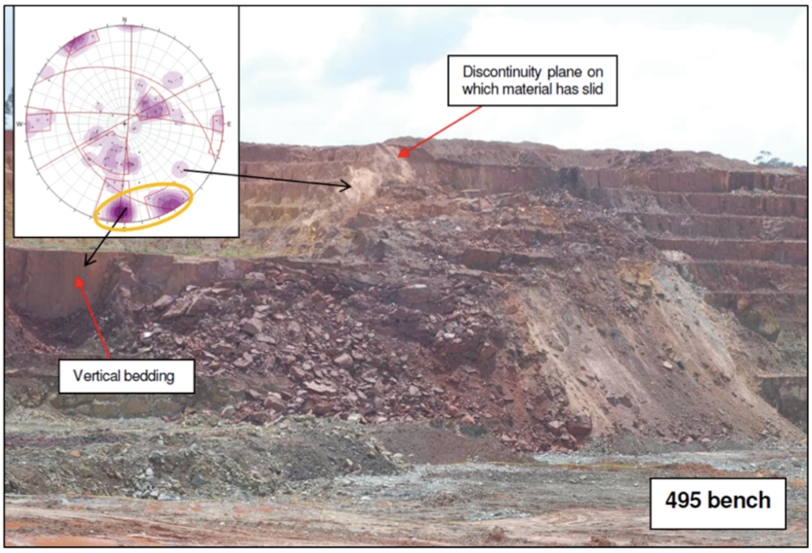

Figure 5 – Complex, toppling-style failure impacted by relict structures in the saprolite and transition

Across all the pits, a total of 30 failures have been recorded in saprolite and transition material. The modes of failure have been mostly toppling, planar, and wedge in that order, indicating the influence of relict structures on saprolite stability. The graph in Figure 6 shows the frequency of the dominant mode of failure in saprolitic material for all those failures that were recorded and analysed.

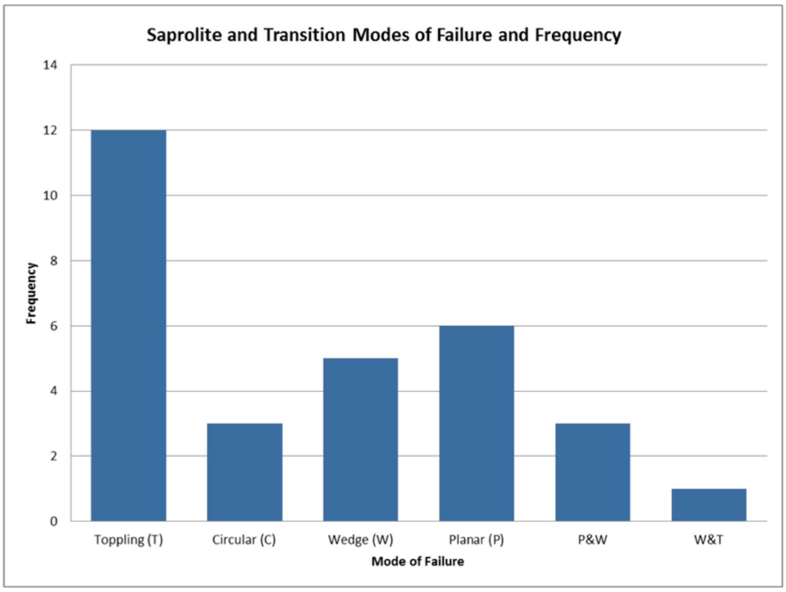

Figure 6 – Graph showing the number of failures observed to date and the primary failure mode. The numerous toppling and planar failures indicate the impact of relict structures on slope stability

Groundwater

The Rosebel area can be described as a high-recharge and moderate to low permeability hydrogeological setting. This leads to a generally localized groundwater flow system with groundwater gradients mimicking topography, and the majority of groundwater being discharged as base flow to streams and wetlands, in relatively close proximity to the point of recharge. During mining the cones of depression are relatively localized due to the high recharge and limited permeability.

The primary control on hydraulic properties is the degree of weathering. The geotechnical weathering classification described above can also be used to define the hydrogeological domains. Figure 7 displays a conceptualization of groundwater flow for an open pit mine located in a deeply weathered tropical environment. The depth profiles for hydraulic conductivity and effective porosity are shown on the left of the figure, and indicate how a large proportion of the groundwater in storage is held within the saprolite. The most permeable horizons sit below the saprolites in what is commonly known as the transition layer, fissured layer, or sap-rock.

The water level response to mining is also shown schematically on the figure, with a sharp reduction in water levels within the more permeable transition zone, leading to under-drainage of the overlying saprolite and the formation of strong downward hydraulic gradients.

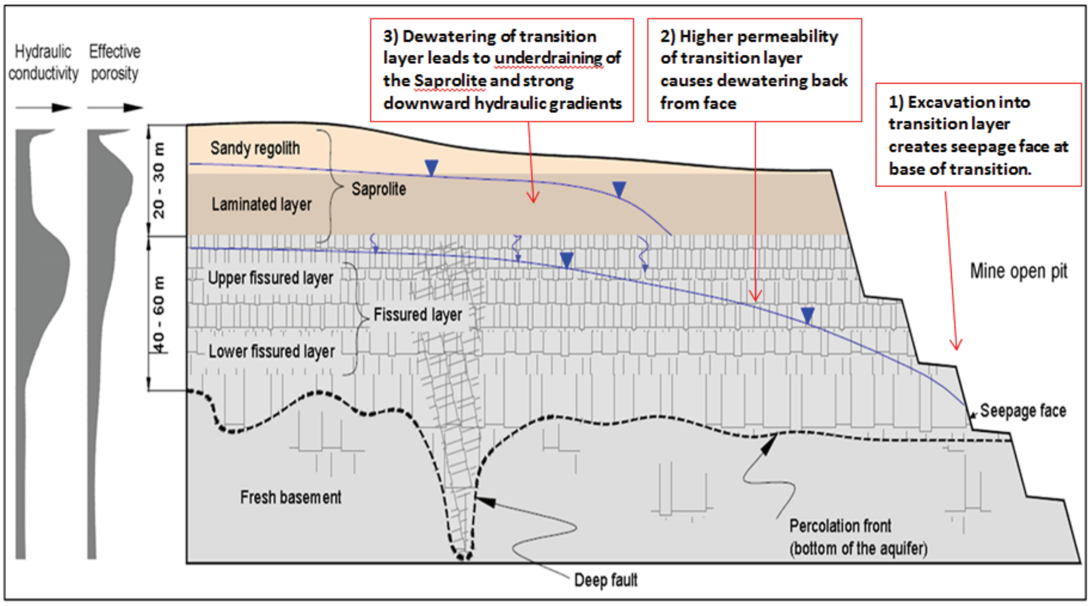

Figure 7 – A conceptualization of groundwater flow for an open pit mine located in a deeply weathered tropical environment. Based on work by Wyns, Baltassat, and Lachassange, 2004; Dewandel, 2006; Elster, Holman, Parker, and Rudge, 2014; and SRK

A network of vibrating wire piezometers (VWPs) has been installed around the open pits at RGM. These VWPs are equipped with data-loggers recording at 4-hourly intervals. The conceptualization of groundwater flow shown in Figure 7 is largely corroborated by the VWP data, with clear responses to mining and strong downward hydraulic gradients evident in the majority of VWP strings. The deep bedrock is seen to depressurize rapidly due to the low groundwater storage. Old exploration drill-holes may also be serving to accelerate depressurization of the deep bedrock where they create a connection with the pit floor. Figure 8 shows an example from the north side of the Rosebel Pit. Strong downward gradients were observed in the VWPs once mining progressed through the transition zone and into fresh rock.

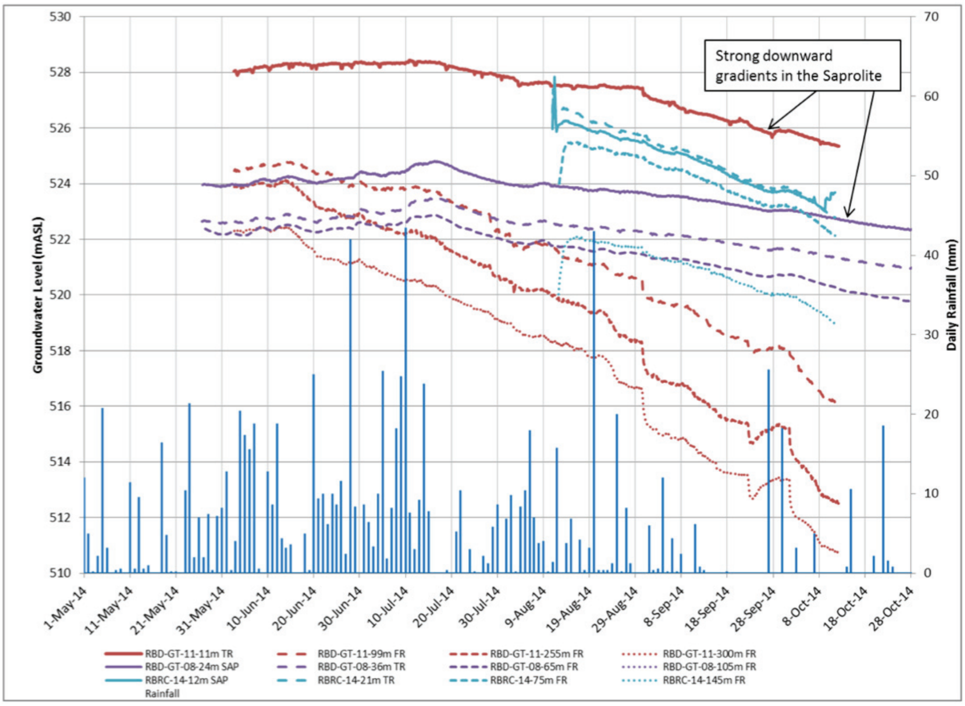

Figure 8 – VWP data from the north wall of Rosebel Pit showing strong downward gradients in the saprolite and transition as mining progresses

The hydraulic properties of the transition are however highly variable, with the relict structures described above having a significant control on groundwater movement in some instances. These structures may cause compartmentalization of groundwater in the transition zone and build-up of pore pressure behind relict structures. There is possible evidence of this occurring on the north wall of the Rosebel Pit where the VWP responses are comparatively muted compared to other areas of the pit (Figure 9).

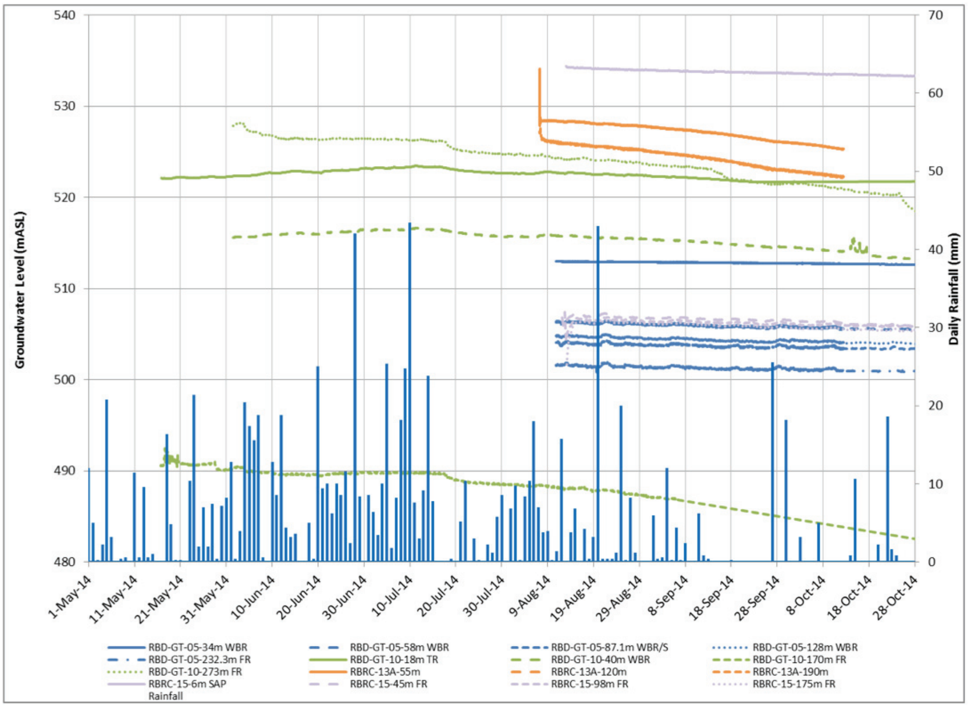

Figure 9 – VWP data from the south wall of Rosebel Pit showing relatively little response to mining in some areas. This is thought to be due to a structure striking immediately behind and parallel to the pit wall

Impact of pit floor location on triggering failures

When assessing the cause of failures it became apparent that high pore-water pressures in the saprolite were a significant factor. A review of historical failures in relation to mining levels showed that the majority of instabilities occurred when the pit floor was still in saprolite. Once the pit floor had advanced to the base of the transition zone or into fresh rock, slope instabilities generally stopped. Furthermore, saprolite slopes that had been creeping over time also stopped moving. The graphs in Figure 10 indicate the recorded saprolite failures and elevations of the pit floor at time of failure relative to the weathering surfaces.

It was concluded that this was likely due to the under-draining of saprolite slopes, leading to a reduction in pore pressures within the saprolite that enabled the slopes to stabilize. VWP data supports this observation in the majority of pit walls, as discussed above.

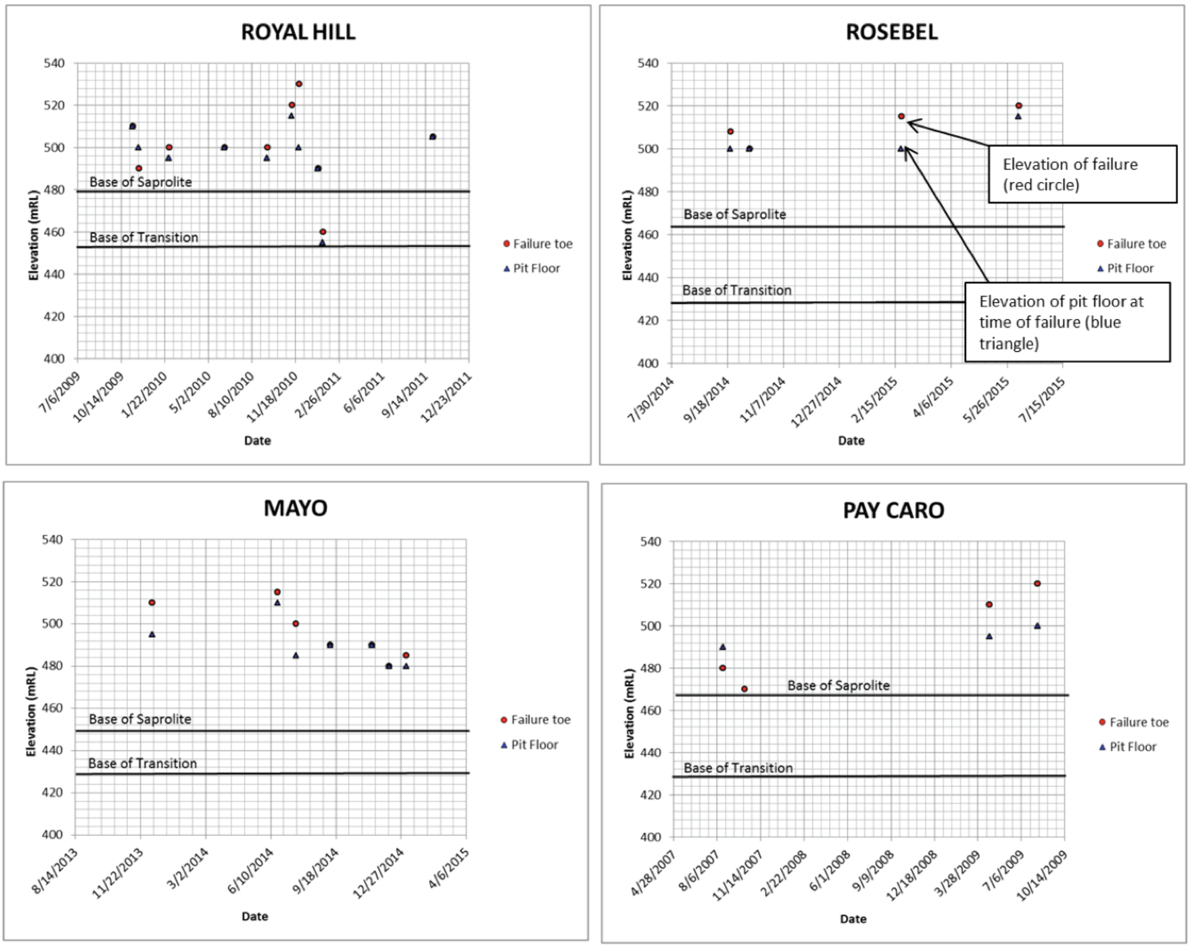

Figure 10 – Plots of saprolite failures (red circles) and elevations of the pit floor at time of failure (blue triangles) relative to the weathering surfaces. The majority of slope failures are seen to occur while the pit floor is still in saprolite

Back-analysis of existing slope failures

To further estimate the saprolite and transition zone strength parameters, 2D back-analysis of existing slopes was undertaken using simple limit equilibrium models. The most reliable analyses were done on slope failures where the groundwater could be incorporated into the analysis with reasonable confidence. An example is given where a 20 m high slope failure in saprolite occurred on the central north wall of Mayo Pit in 2013 (Figure 11). The failure impacted four benches below an access ramp. Tension cracks were seen in the ramp and eventually the ramp was closed. The failure was likely caused by ponded water in a drainage ditch on the ramp saturating the slope. Also, there was water ponding in the pit floor, likely saturating the toes.

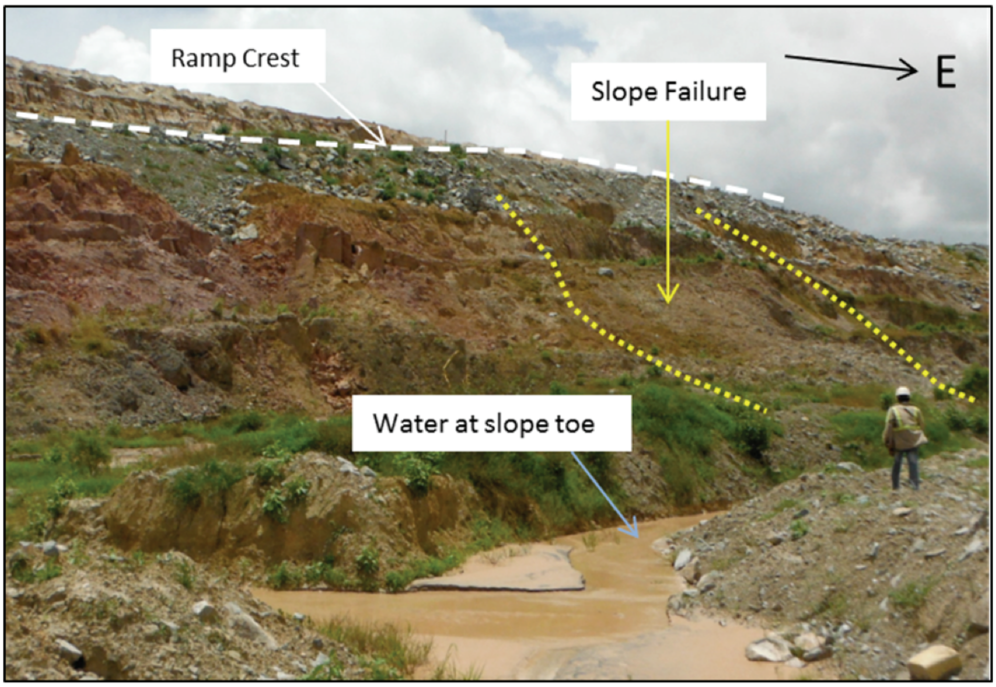

Figure 11 – Slope instability in saturated saprolite slopes on the northern wall of Mayo Pit

A simple 2D back-analysis of this failure was undertaken to estimate the cohesion of the saprolite. The friction angle was set at 24° (determined from laboratory testing) and the water table drawn with reasonable confidence from the drainage ditch to the slope toe, where ponded water was observed. The cohesion was varied until a factor of safety (FoS) of 1 was achieved. Results gave a cohesion value of approximately 20 kPa.

Numerical modelling

2D stability analysis of saprolite and transition slopes was done using a limit equilibrium approach in Slide. The purpose of the analysis was to:

- Determine suitable inter-ramp angles for saprolite and transition slopes
- Determine suitable stack heights
- Investigate the sensitivity of the slopes to groundwater, and determine a suitable depth into rock the pit floor must be advanced in order to achieve the necessary amount of under-draining for slopes to remain stable.

The strength parameters of saprolite and transition material were very difficult to determine accurately, since they change both with depth and along the strike of a slope. Therefore a probabilistic analysis was undertaken to represent the uncertainty in the strength parameters. The saprolite was modelled assuming an isotropic soil mass, and the transition material was modelled using the anisotropic strength function to incorporate the influence of relict structures. The critical relict structures used in each section were identified from the pit mapping and oriented core drilling. A Mohr-Coulomb failure criterion was considered the most applicable; since the traditional Hoek-Brown criterion is known to break-down at GSI values of less than 25 (Martin and Stacey, 2013) and would likely over-estimate the shear strength parameters (Fietz *et al*., 2011).

Typical input parameters chosen for saprolite and transition stability analysis are shown in Table II.

Table II. Saprolite and transition slope modelling input parameters

Material	Failure criterion	Unit weight (kN/m^3)	Friction angle (°)	Cohesion (kPa)
Saprolite	Mohr-Coulomb	18	20-30	15-35
Transition	Mohr-Coulomb	20	30-40	50-70
Relict structures	Mohr-Coulomb	n/a	15-25	0-25

Incorporating groundwater into the models

Review of existing slopes shows that groundwater is a critical factor in saprolite and transition slope stability. As discussed, the VWP data suggests that by mining staggered benches, suitable depressurization of the slopes could be encouraged without the need for horizontal drains. Analysis was undertaken to determine how deep into rock the pit floor should be to allow suitable under-draining, before final saprolite/transition slopes can be cut. Stability models were run using pore pressure grids imported from transient pore pressure models. An example of the stability model is shown in Figure 12.

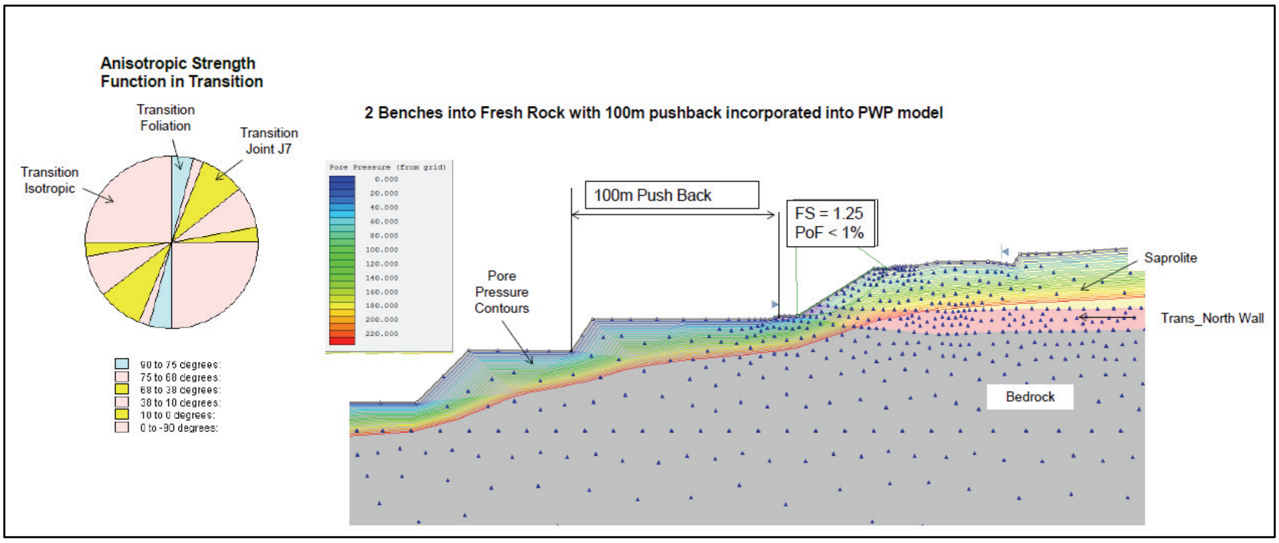

Figure 12 – Example of stability model showing the anisotropic strength function applied to transition material and contours of pore pressure grid for a 100 m push-back

Results indicated that mining two benches into fresh rock within approximately 150 m of the final push-back would allow sufficient under-drainage to occur such that final steeper slope angles could be cut.

The modelling approach is a simplified representation of a complex scenario. Some additional factors relating to stability were considered when generating final slope designs, as outlined in Table III. These factors are difficult or impossible to accurately quantify and therefore were not incorporated in the stability modelling. However, their potential impact on design and how they have been addressed are also detailed in Table III.

Table III. Additional factors impacting saprolite and transition slope performance

Factor	Impact on slope performance	Comments
Matric suction	Partially saturated slopes will exhibit some degree of matric suction which will enable steep batters to be obtained. Determining the degree of matric suction is extremely difficult and will vary with time and amount of surface water infiltration	Matric suction may decrease over time due to intense rainfall (increasing pore pressure from negative value towards zero), potentially increasing the likelihood of failure. Conversely however, the slope will also drain as mining advances reducing the likelihood of failure.
Cementation	Cementation within the saprolite and transition will increase with depth; therefore cohesion will also increase with depth. Cohesion values chosen in the models are considered to be representative, but it may be that much higher values exist, particularly in the drier season.	Stability models may be conservative in areas where higher degrees of cementation and therefore cohesion exist. The probabilistic approach to modelling has incorporated a spread of cohesion values to mimic this situation. In addition, the design approach also incorporates a review of existing saprolite and transition slopes at Rosebel, not purely the results of numerical modelling.

Saprolite and transition slope design

Saprolite and transition slope design sectors were generated for each pit. Design sectors were governed primarily by the presence of relict structures in relation to wall orientation and depth of the weathering profile.

Benches in saprolite will be free-dug using the excavator and cut back to the desired bench face angle. From a review of existing bench faces at the Rosebel property it was recommended that a BFA of 60° be used for all saprolite slopes. This represents a balance between minimizing erosion from surface water runoff (steeper bench faces being more favourable) and maintaining stability (where shallower bench faces are more stable). Keeping the BFA consistent for all pits also makes the design more practical to implement.

Saprolite bench heights are to be 8 m. Benches are cut in either two 4 m flitches or a single 8 m cut depending on the size of equipment operating. 8 m bench heights are required to make them the same height as the transition benches. This enables a surface water management plan to be implemented. Crest dig lines are marked with flagging tape to ensure the machine operator cuts the benches to the required width. Stack heights in saprolite are limited to 32 m. Where Saprolite thickness is greater than 32 m, a 15 m wide geotechnical berm is implemented to decouple the slope and manage surface water. Final inter-ramp design angles in the saprolite were around 32° for most pits.

Final inter-ramp design angles in the transition zone varied from 32° to 40° depending on presence or absence of unfavourably oriented relict structures and parent rock fabric. For example where a subvertical foliation existed, slopes parallel to that foliation would be around 32°. However, where foliation strikes into the wall, final angles would be up to 40°. Transition stack heights are limited to 40 m before a 15 m geotechnical berm is required. Where the weathering surface is undulating within a design sector the step-in is located at the lowest elevation.

Transition zone is excavated in single 8 m benches using a modified production blast. The buffer row is kept a suitable distance from the bench toe in order to keep the zone of crushed material from extending beyond the planned batter face. The excavator can then define the bench face angle by free-digging any un-blasted material. As with the saprolite, crest dig lines are clearly marked to prevent any reduction in the berm width.

Interim slopes and staggered benches

High pore-water pressures are known for causing instabilities in the saprolite and transition at Rosebel. Implementing a complex horizontal drainage system across so many pits would be time-consuming and expensive. The design approach used here is to mine shallow interim slopes, typically at inter-ramp angles of less than 28° until the pit floor is in fresh rock. This allows under-draining to occur and depressurization of the saprolites. For the final push-back the saprolite and transition slopes can then be steepened to the ultimate design angle provided. When cutting the final slopes the push-back distance between transition toe and fresh rock crest should be limited to less than 100 m to ensure the saprolite and transition can still under-drain into the fresh rock. This 100 m threshold is used for guidance purposes; pore pressure data from VWPs can be used to refine this guidance on a sector -by-sector basis.

In addition it was found to be critical that mining is done on staggered benches across the pit, with at least one bench in rock. Mining one long bench in saprolite, for example, resulted in surface water issues, trafficability issues, and often causes interim slope failures. Staggered benches have been successfully implemented in Mayo pit where mining is operating at three different elevations: the pit floor is in fresh rock at the east end, and saprolite at the west end (Figure 13).

Figure 13 – Staggered benches in Mayo Pit resulting in manageable working conditions during the wet season; and stable saprolite slopes (looking south)

Surface water management

Review of existing saprolite slope performance shows how critical good surface water management is in preventing gullying and erosion of multiple benches. However, when operating numerous pits simultaneously it is important that the surface water management plan is still economical and practical to implement given the resources available. The recommended surface water management plan included:

- Placing a HDPE-lined diversion ditch a minimum of 30 m behind the pit crest to prevent water feeding the pit slopes
- Saprolite berms should be graded at 2–3% into the pit to encourage sheet flow of water across benches and onto the geotechnical berms or ramps
- A 15 m step-in is required at the transition/rock contact (and at maximum stack height) which must contain a drainage ditch to catch the sheet flow
- Geotechnical berms with ditches are then graded laterally to carry water across the benches to a sump either at the pit bottom or at an appropriate location on the geotechnical berm. Water from a sump on a geotechnical berm is then either pumped directly out of the pit or piped to the main sump in the pit bottom.

Conclusions

Saprolites are complex materials with variable geomechanical behaviour that is not fully understood. This paper presents a design approach used for generating slope configurations and practical implementation requirements in saprolite and transition material at the Rosebel Gold Mine. The approach taken was to review existing slopes in the various geotechnical domains to identify primary causes and modes of failure. Simple numerical modelling was used to add confidence to the slope designs using strength parameters estimated from back-analysis and laboratory testing.

Controlling factors in saprolite and transition slope performance at Rosebel were found to be orientation of relict structures, elevated pore-water pressures, and surface water runoff.

Interim slopes are mined at flatter angles until mining has progressed down into fresh rock allowing under-draining of the saprolites to occur without the need for more complex depressurization techniques. A network of VWPs is in place to verify that such under-drainage is occurring and final slopes can then be cut to the steeper design angles once the pore pressures are significantly reduced. Mining the pits in staggered benches enables good surface water management, reduced trafficability issues, and prevented saturation of saprolite slope toes.

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