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Geotechnical management of large scale slope deformations at the Teal Gold Project, WA

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ABSTRACT: This case study demonstrates the ability to successfully operate beyond conventional open pit slope performance criteria at the Teal open pit gold mine near Kalgoorlie, Western Australia. The majority of the east wall of the open pit deformed in a ductile manner as mining progressed to the target depth of 50m. Maximum total displacements were in the order of tens of meters and cracking was observed up to 90m behind the crest of the pit. Rates of wall displacement in excess of 10mm per hour were experienced during mining. The slope deformations experienced at the Teal open pit were successfully managed as a result of highly responsive geotechnical slope design and management. Design modifications included partial unloading and changes to excavation sequencing to limit deformations and to prevent ore sterilisation. Slope management comprised of prism and slope stability radar monitoring, a carefully developed trigger action response plan (TARP) and equally importantly, proactive mining operations. The application of slope stability radar monitoring allowed the operational management of slope deformations in excess of historically achievable rates. The pit was successfully completed at the planned metal grades, with a 5% surplus in ore mined.

1 INTRODUCTION

This case study demonstrates the ability to successfully operate beyond conventional open pit slope performance criteria at the Teal open pit gold mine near Kalgoorlie, Western Australia.

The Teal Gold Project is a small scale open pit gold mine located 11 km North West of Kalgoorlie, within the Goldfields region of Western Australia as shown in Figure 1. The open pit was mined for approximately 18 months, up to early 2018. The open pit is approximately 500m long x 150m wide, and was mined to a depth of approximately 50m.

This paper is focused on the geotechnical slope performance, slope remediation and pit slope management in response to high deformations experience in the eastern wall of the pit.

Pells Sullivan Meynink was engaged to provide specialist geotechnical advice for the project. This advice included site investigations, pit slope design parameters and operational support. Operational support comprised ~~of~~ site inspections, remote radar monitoring, development of a ground control management plan (GCMP), and later a trigger action response plan (TARP).

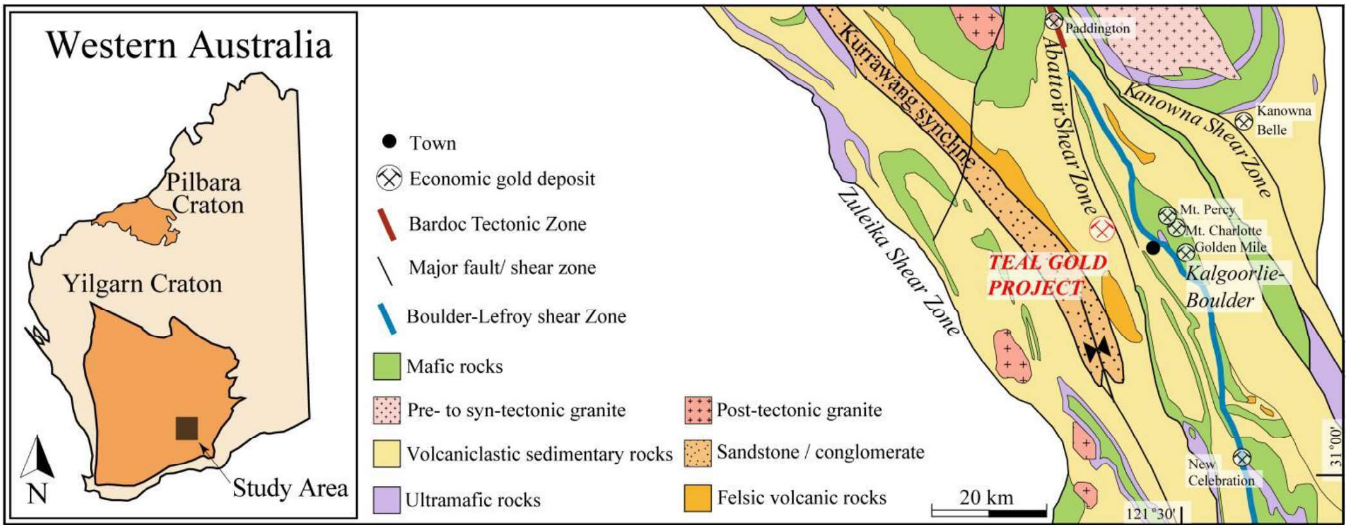

Figure 1. Locality and regional geology map (After Morey et al 2007).

2 GEOLOGY

The Teal Gold Project is located 700m west of the north-northwest trending Abattoir Shear Zone as shown in Figure 1. Locally, the geology consists of transported sediments overlying caprock and a weathered, foliated sequence of felsic tuffs, porphyries and intermediate volcanics. The volcanic sequence is completely weathered to residual saprolitic clays to depths of up to 60 m (i.e. below the final pit floor). The dominant structural fabric of these rocks is a sub-vertically to steeply south west dipping relict foliation. The water table was intersected towards the base of the pit.

Gold mineralization is encountered as an upper supergene zone and a lower hypogene orebody at depth. Mineralisation is thought to be structurally controlled along major shears and splay fault structures.

3 GEOTECHNICAL MODEL

3.1 *Site Investigation Philosophy*

Geotechnical model development and slope design was based on a limited geotechnical investigation, with a view that uncertainties would be addressed during the early stages of mining with trial slopes and a "mine and manage" approach to slope stability.

The geotechnical site investigation comprised two geotechnical boreholes with a total length of 145m. The HQ3 diameter boreholes were inclined at 60° and drilled into the east and west walls near the southern end of the proposed pit as shown in Figure 2. Figure 2 presents an engineering geological plan of the Teal Gold Project, including:

- Borehole traces,
- Final pit contours,
- Tension cracks, and
- Reported instabilities.

Limited field and laboratory testing included:

- Point load and pocket penetrometer testing of core, and
- Particle size distribution, Atterberg limits and Emerson Class testing of four disturbed soil samples.

Standpipe piezometers were installed in the two geotechnical boreholes and open resource boreholes were dipped to collect water level data.

Effective strength parameters were estimated from the results of the site investigations and testing listed above.

3.2 *Geotechnical Model*

The geotechnical model was developed based on a combination of the resources model and the geotechnical drilling. Three geotechnical rock mass domains were defined as shown on the interpretive geotechnical cross section presented in Figure 3. The three geotechnical units are described below:

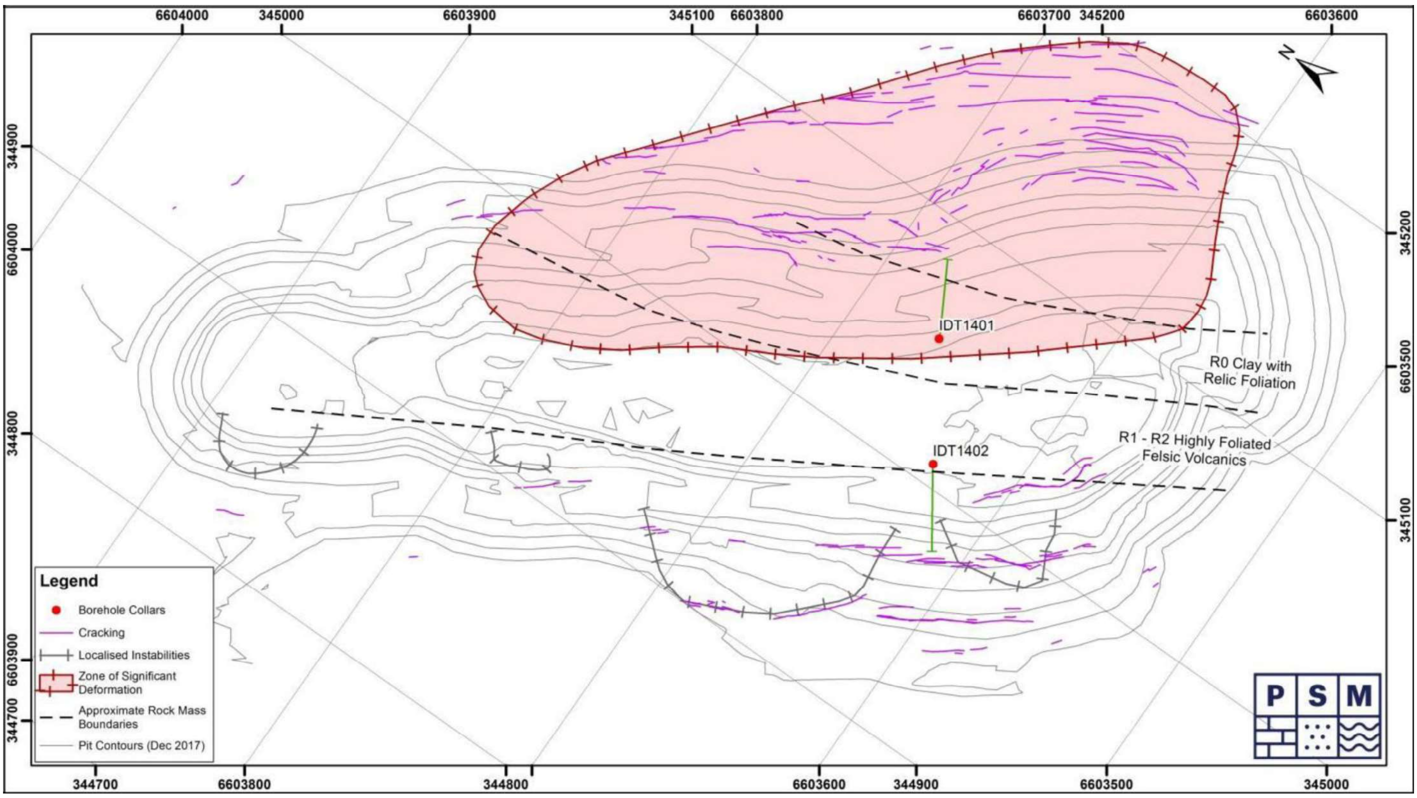

Figure 2. Teal Gold Project site plan, showing instabilities and observed tension cracks.

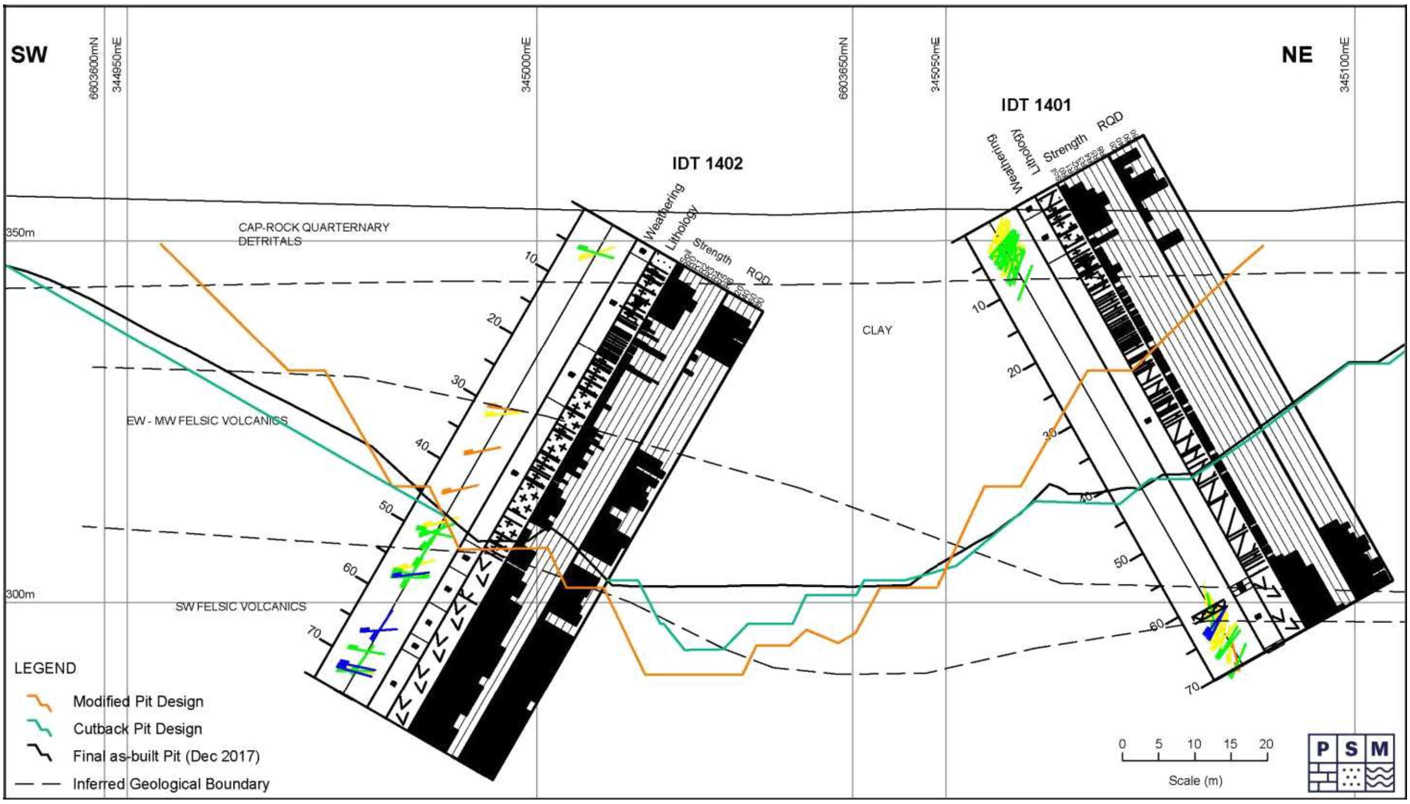

Figure 3. Interpretive cross section of the Teal Gold Project, showing the deep clay weathering profile. Section faces northwest.

1. Cap-rock: Typically the upper 10m of the deposit. Variably cemented sandy clay and weathered rock. Typically R1 to R2 strength, with a logged RQD of 80 – 100 %.
2. Clay: Stratigraphically below the cap-rock. Variable thickness of up to about 60m in the east wall. Typically R0 strength however some zones of S3 to S4 strength, > 85 % fines, low liquid limit silt (from Atterberg limits testing), however logged as moderately plastic clay, low dispersivity and slaking potential.
3. Weathered felsic volcanics: Metamorphosed fine to medium grained felsic volcanics. Extremely to moderately weathered, R1 to R2 strength. Steeply south west dipping, wavy foliation with clean or iron stained partings. Logged RQD of 60 – 85 %.

The groundwater table was estimated to be approximately 40m below the ground surface. Permeability in the clay units was interpreted to be relatively low, and any natural drainage from slope was expected to be limited.

4 GEOTECHNICAL ANALYSIS AND SLOPE DESIGN

A suite of limit equilibrium slope stability analyses was undertaken to estimate the recommended slope design parameters. The recommended overall pit slope angle was assessed to be 40° on the western pit wall and 32° on the eastern pit wall. Bench slope configuration is provided in Table 1.

Table 1. Bench Slope Configurations

Geotechnical unit	BFA*	BW*	BH*
	°	m	m
Caprock	65	10	10
Clay	45	10	20
Weathered felsic volcanics	65	8	20

* BFA: Bench face angle, BW: Berm with, BH: Bench height.

Key uncertainties in the slope design included:

- The vertical and lateral distribution of geotechnical units across the deposit. This uncertainty is greatest to the north, away from the geotechnical drilling,
- Structure and material strengths particularly of the clay unit and its depth,
- The extent of depressurisation required, and
- The risk of instability associated with discrete structures such as faults and shears.

To manage the uncertainties identified, the following geotechnical risk management strategy was recommended:

1. A starter pit with trial slopes.
2. Relocation of the haul road to the eastern wall of the ultimate pit to flatten the higher risk slopes excavated in deeper weak clays.
3. Regular geotechnical pit inspections and pit slope management advice.

5 GEOTECHNICAL RISK

Design modifications in the intervening period between the geotechnical slope design and the commencement of mining resulted in incremental increases in the geotechnical risk profile for the project. These modifications were:

1. Relocation of the haul road from the east wall to the west wall of the pit.
2. A consequent increase in overall slope angle on the eastern pit wall from 32° to 46°.
3. Commencing excavation of the ultimate pit, thus committing to final slopes with aggressive slope angles.
4. Increasing the pit strike length.

These design modifications, combined with the encountered geotechnical conditions resulted in an increased geotechnical risk for the operation. The modified pit design is shown in Figure 3 and a discussion of the increased risk is presented in Sec-tion 7.

6 PIT SLOPE MANAGEMENT

Pit slope management is an essential component of successful open pit mining, particularly in challenging conditions. A detailed Ground Control Management Plan (GCMP) was developed to manage the operational geotechnical risks at the Teal open pit as outlined below:

1. Regular walk over inspections of pit walls to detect signs of ground deformation and instability. This included cracking, slope bulging and toe heave.
2. Documentation of geotechnical observations and the location of any cracking or failures both on plans and in a geotechnical register.
3. Increased frequency of inspections following the identification of instabilities.
4. Geotechnical monitoring comprising of prisms and slope stability radar.
5. Geotechnical mapping of pit exposures, with a focus on material strengths and structure in both soils and rock.
6. Measurement of groundwater levels in slopes.

7 SLOPE DEFORMATION, MONITORING AND REMEDIATION

7.1 *Introduction*

Conventional open pit slope design assumes a level of slope performance which is commonly expressed as probability of failure for inter-ramp and bench scale performance of not exceeding say 5% and 30% of the slope area respectively.

Significant slope instability was observed during mining. Approximately 75% of the eastern pit wall and 30% of the western pit wall deformed during mining as shown in Figure 2. Photo 1 shows an example of slope instability along the western pit wall. Photos 2, 4 and 5 show examples of instabilities along the eastern pit wall.

7.2 *Failure Mechanism*

The major failures at the site were interpreted as sliding and dislocation along the steep relict foliation, with toe shearing through weak clays. A key issue for the management of these failures was the requirement for ongoing mining operations below the instabilities.

Photo 1. Observed instability along the western pit wall.

7.3 *Failure Remediation*

Remedial slope modifications primarily comprised unloading of the crest and strategic toe buttressing of the eastern pit wall to reduce rates of deformation. Photos 2 and 3 show the eastern pit wall before and after unloading of the slope through the use of a cutback. Photos 4 and 5 show deformation observed along the eastern pit wall after the cutback was excavated.

To minimize the loss of ore, cutbacks were preferred to a step in of the design. A suite of limit equilibrium analyses were conducted to assess the unloading requirements, and the area was monitored post remediation to confirm the analysis results.

The cutback along the eastern pit wall also included a second ramp access to the pit, reducing the risk of complete loss of access to the open pit and decreasing the overall slope angle for the eastern pit wall.

Photo 2. Eastern pit wall before slope unloading, showing the large scale instability and strategic buttressing material (midground).

Photo 3. Eastern pit wall after slope unloading and approaching the completion of mining.

Photo 4. Head-scarp of the eastern pit wall instability at the completion of mining.

7.4 *Pit Slope Monitoring and Trigger Action Response Plan (TARP)*

Slope monitoring initially comprised of geotechnical inspections and prism monitoring. As the eastern pit wall buttressing material shown in Photo 2 was excavated, slope deformation rates increased significantly, reaching peak deformation rates of greater than 10 mm/hr.

The increased deformation rates and exposure ultimately resulted in an increased risk to personnel and equipment in the area. Commensurate with this increased risk, operational geotechnical management was expanded to include more frequent inspections, slope stability radar monitoring and the development of a TARP to control access to the areas at risk of possible failure and run out.

Deformation of the eastern pit wall continued until the completion of mining, with total displacements of over 10m and cracking observed up to 90m behind the crest of the eastern pit wall as shown in Photos 4 and 5.

The TARP was continuously implemented from the commencement of mining the material left in place to buttress the eastern pit wall, until the completion of mining the east wall cutback to the planned final depth of 50m.

The application of precise slope stability monitoring radar at the Teal project allowed for the management of pit slopes deforming in excess of historically manageable rates.

The final excavated slopes achieved overall slope angles of up to 31° on the eastern pit wall and 39° on the western pit wall. Table 2 presents the overall slope angle progression throughout the project life.

Photo 5. Eastern pit wall instability at the completion of mining.

Table 2. Slope Angle Progression

Project Stage	Eastern Wall °	Western Wall °
PSM slope design	32	40
Modified pre-cutback angle	46	-
Final overall angle	31	39

8 CONCLUSIONS

This case study demonstrates the ability to successfully maintain safe mining operations well beyond the conventional open pit slope performance criteria.

This was achieved through focussed and expert geotechnical advice regarding slope design and operational management. The slope design advice comprised:

1. Partial unloading of the deforming slope, and
2. Changes to excavation sequencing in order to limit deformations, and minimise ore sterilisation.

In conjunction, the operational slope management advice included:

3. Geotechnical monitoring comprised of real time slope stability radar, supported by conventional prism monitoring.
4. Development of a detailed GCMP,
5. Regular geotechnical inspections,
6. A carefully formulated and actively revised TARP, and
7. Effective communication of operational slope management advice to mining operations personnel.

The Teal open pit was successfully mined to the planned depth of 50m and at the planned metal grades, with 5 % additional recovered ore tonnage.

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