Mine groundwater control and slope depressurisation methods at Ok Tedi in one of the highest annual rainfall areas in the world

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Abstract The Ok Tedi Mine is located in the Western Province of Papua New Guinea. The average rainfall (1985—2010) is between 8m and 10m per annum with a maximum of 10.7m (2005) and minimum of 4.7m (1997). From 2007, boreholes have been drilled and fully cemented vibrating wire piezometers with data loggers were installed in these holes to monitor the piezometric head in the different lithologies. Packer tests to estimate hydraulic conductivity values were conducted. The software FEFLOW and Phase^2 were utilised to model the pore pressure distribution in the pit walls and the results were used to access the pit wall stability.

Key Words 8m rainfall, high walls, vibrating wire piezometers, drain holes, depressurisation

Introduction

The Ok Tedi Open Pit Mine is located at the headwaters of the Ok Tedi River, in the Star Mountains of the Western Province of Papua New Guinea (see Figure 1).

Daily rainfall records in the project area are available from 1985 onwards. The average rainfall in the period 1985—2010 is between 8m and 10m per annum (depending on the position of the rainfall gauge) with a recorded maximum of 10.7m (2005) and minimum of 4.7m (1997) as shown in Figure 2. Rainfall is relatively evenly distributed over the year with the maximum occurring during July and the minimum during November. The actual average annual evapotranspiration for the pit area is estimated at 656 mm/annum (OTML, 1999).

Geology and Hydrogeology

The oldest sediments at Ok Tedi are sediments of the Ieru Formation. The Ieru Formation comprises dark grey to black mudstones, shales, siltstones and sandstones, laid down on a predominantly near shore shallow marine shelf during the Upper Cretaceous (Aptian – Seronian). The Ieru Formation is overlain by the Darai Limestone (Eocene – Lower Miocene). The nature of the contact between the two units is uncertain. The Darai Limestone consists of foraminiferal limestones, mudstones and wackestones of a shallow marine facies. The Darai limestone exhibits widespread evidence of solution enlargement of vertical joints and cave (karst) systems are known in several locations, the most notable of which is the Harvey Creek Cave Spring (HCCS). This is devel-

***Figure 1** Ok Tedi Locality map.*

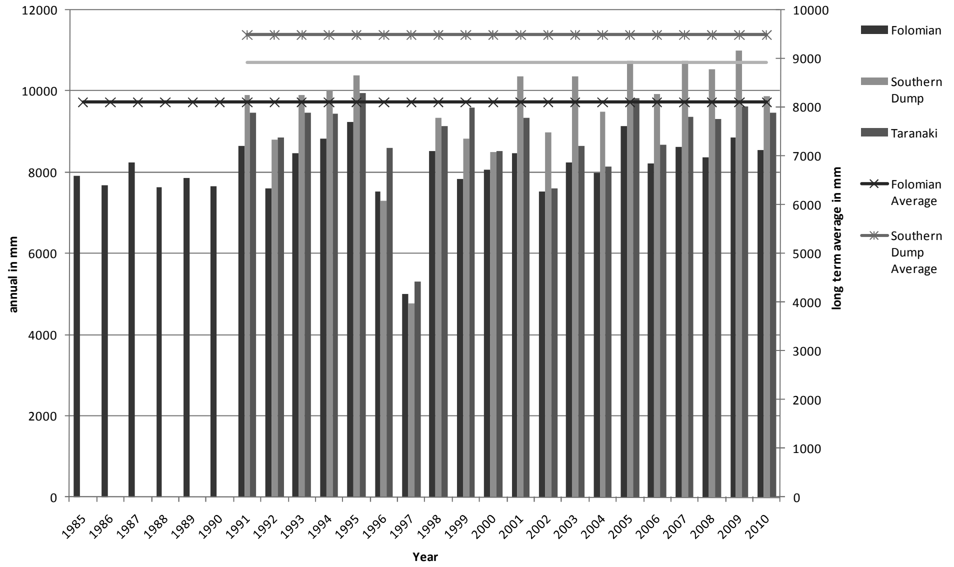

Figure 2 *Annual Precipitation Data – Ok Tedi Mine.*

oped in the lower unit under the Moscow Sector. Larger sinkholes have been uncovered periodically during mining, particularly in the upper unit on the west wall; one of which was large enough to engulf an excavator (OMTL, 1999).

The Darai Limestone is overlain by the Pnyang Formation (Middle Miocene). This Pnyang Formation consists of mudstones, siltstones with subordinate limestone lenses.

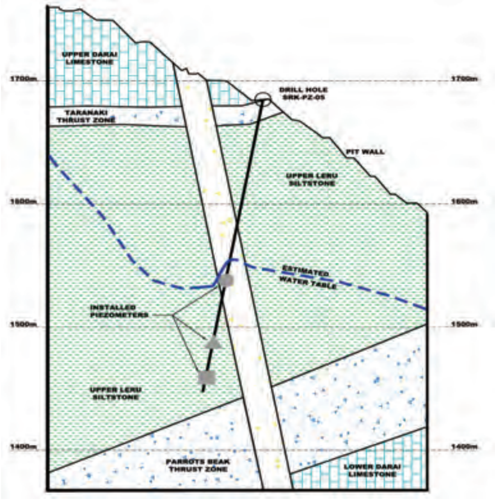

Figure 3 *Geological section (W-E) through borehole PZ05.*

The sediments in the Ok Tedi area were subjected to major thrust faulting and folding prior to the placement of the intrusive. Emplacement of the Pliocene Sydney Monzodiorite is believed to have produced the Ok Tedi skarns through metasomatic replacement of limestone/carbonate facies by reaction with magmatic fluids. The Sydney Monzodiorite is relatively unaltered and contains limited economic gold and copper mineralisation, although it is enriched near the Fubilan monzonite porphyry contact. The fault network provided conduits for magma and intrusion by multiple phases of variably mineralised calc-alkaline stocks with contemporaneous skarn formation.

Although numerous exploration, geotechnical and dewatering boreholes have been drilled over the past 30 years, only an extremely limited number are currently being used to monitor the hydrogeological environment in and around the mine. From 2007 to February 2010, fifteen boreholes have been drilled for the specific purpose of hydrogeological monitoring. Fully cemented vibrating wire piezometers with automatic data loggers were installed in these holes to monitor the piezometric head in the different lithologies (see Figure 3 and Figure 4). More than 30 packer tests to estimate hydraulic conductivity values were conducted in >10 boreholes over the past years.

Using groundwater level monitoring data the piezometric surface throughout the mine was created using the contouring software Surfer and incorporated into a wireframe surface using

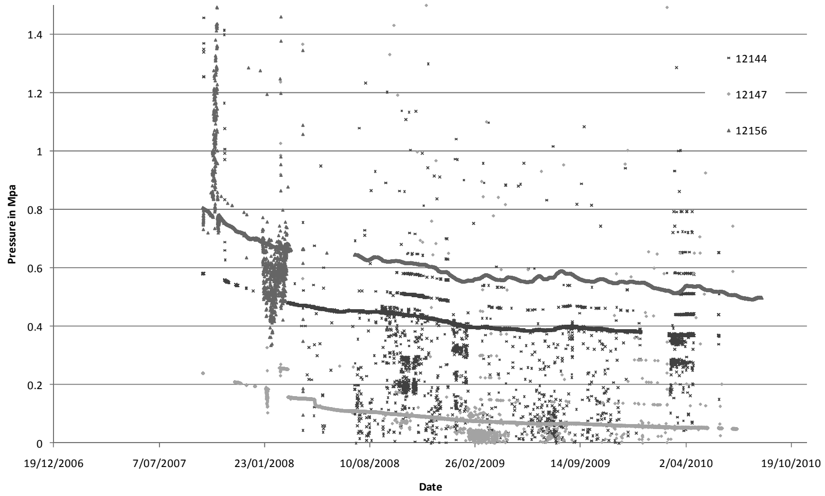

Figure 4 Pressure head monitoring data of borehole PZ-05.

Mine2—4D. When the groundwater level wireframe is overlain with the current pit development wireframe (see Figure 5) the seepage face can be seen. Seepage outside this area (e.g. higher up the face) represents unsaturated seepage flow from recharge events. It is evident that most of the central and northern part of the pit is currently in a state of equilibrium. Inflow into the system equals the outflow of the system. However, considering the planned increased dropdown rate of the pit bottom, the passive depressurisation rates of the high wall might not be adequate and active dewatering measures must be implemented to reduce the hydraulic head. The relationship was studied using a program of geotechnical and hydrogeological modelling.

Geotechnical and hydrogeological modelling

An appropriate phased modelling approach was devised in order to provide the most suitable in-

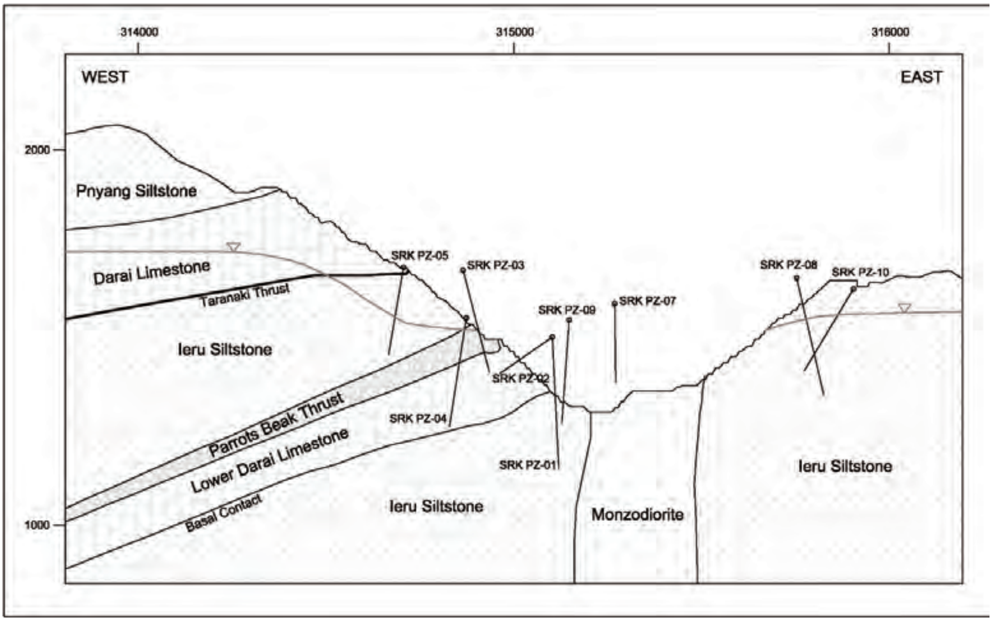

Figure 5 *West-East section through the open pit viewed from the south.*

puts to the final UDEC (discrete element) analyses of the West Wall Cutback intended at OK Tedi. This approach included the following steps:

1. Slope stability analyses of two sections by means of Phase^2 small-strain finite element analysis was conducted to determine the approximate position (i.e. distance behind the face) of the groundwater level and the pore pressure distributions required in order to obtain a Factor of Safety (FoS) of approximately 1.3 or greater.
2. 2-D and 3-D hydrogeological modelling by means of FEFLOW software to determine the drainhole configurations required in order to achieve the groundwater level that the Phase 2 modelling had indicated to allow for a stable West Wall Cutback.
3. The results of the FEFLOW model were than used as real pore pressure data in a subsequent Phase^2 slope stability analysis.

Rock mass strength, rock fabric and hydraulic input parameters were based upon an extensive laboratory and field test program between 1997 and 2010 (OTML 1999, SRK 2006, 2007, 2010) in collaboration with OTML staff.

Variations in groundwater conditions were used in both sections to study the requirements for dewatering/depressurisation for the pit wall stability. These are listed in Table 1 and the position is shown in Figure 6.

For each analysis, plots of total displacement and maximum shear strain were used to assess slope performance. The FoS in each case is determined by means of the strength reduction process and thus is expressed by means of the Strength Reduction Factor (SRF). The first-pass stability results are summarised in Table 1. These results show that a the piezometric surface needs to be pushed back to around 150m behind the southern part of the pit wall and 200m behind the central/northern part of the pit wall, in order for suitable FoS to be achieved.

Initial 2-D FEFLOW seepage and depressurisation analyses were carried out to investigate the passive drainage requirements (horizontal drainholes) that must be employed to obtain piezometric surfaces of approximately 150m and 200m behind the West Wall as predicted by Phase 2 analysis. Separate sets of analyses were carried out for each section, in order to assess the effectiveness of various drainhole configurations. Vertical drainhole spacings of 120m (i.e. drainholes at the base of each bench stack) were assessed, with drainhole lengths of 150m, 200m and 300m.

Numerous dewatering/depressurisation boreholes hole have been drilled into the west wall over the past years and are still drilled. Based on the the current monitoring data it seems to be having a positive impact as the piezometric head is lowering on an annual basis. Based on all these observations there does not seem to be an excessive built up of water behind the west wall and the saturated piezometric surface is ±200m away/behind the western high wall. This means that current dewatering and depressurisation measures are resulting in reduced pore pressure and this is leading to an improved stability of the west wall.

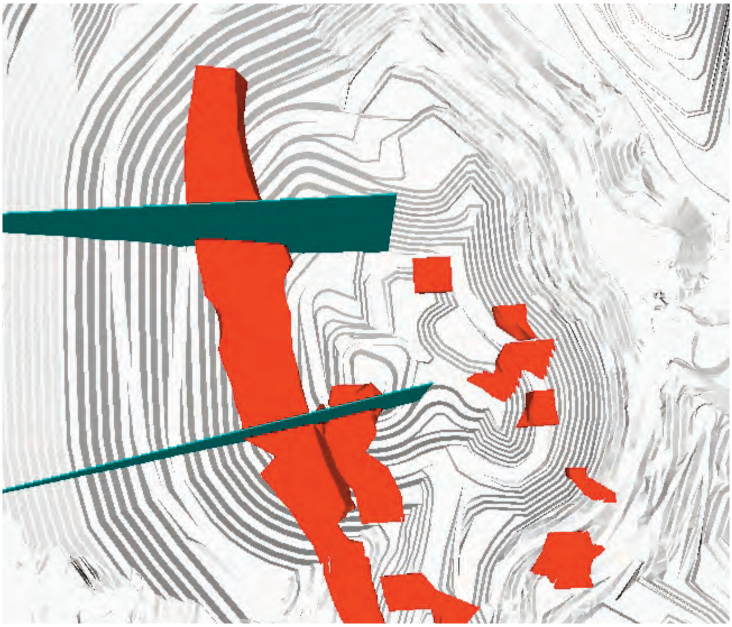

Figure 6 *Positions of the sections.*

Table 1 *Different groundwater conditions used for pit wall stability assessment.*

Section	Groundwater Conditions	Critical SRF
1	Worst case groundwater level (piezometric surface almost at pit wall)	1.02
	150m pushback of piezometric surface behind wall	1.36
	200m pushback of piezometric surface behind wall	1.46
	300m pushback of piezometric surface behind wall	1.55
2	Worst case groundwater level (piezometric surface almost at pit wall)	0.88
	150m pushback of piezometric surface behind wall	1.21
	200m pushback of piezometric surface behind wall	1.32
	300m pushback of piezometric surface behind wall	1.41

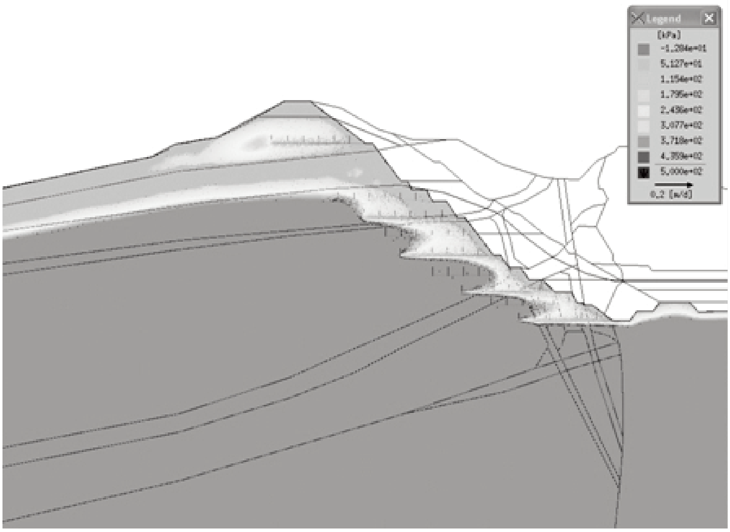

Figure 7 *Pore pressure distribution with drainholes at 120m vertical spacing, and horizontal spacing 30m, comparing unsaturated flow for 300m long horizontal drains.*

Summary and Preliminary Conclusions

From the hydrogeological and slope stability numerical analyses completed so far, the following can be concluded:

Several types, sets and phases of analyses were conducted to build a logical and orderly sequence of results (and to test sensitivities) in order for preliminary establishment of the most suitable passive drainage requirements for ensuring suitable stability of the West Wall Cutback.

The slope stability analyses and 2-D hydrogeological analyses have been conducted on selected sections and the quasi 3-D hydrogeological analyses have been conducted on blocks of limited extent.

A drainhole length of 300m, horizontal drainhole spacing of 30m and vertical drainhole spacing of 120m is necessary to accomplish a pushback of piezometric surface behind the wall of 150m and 200m (see Figure 7) to achieve a FoS of ≈ 1.3.

Acknowledgement

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