Measuring Discontinuity Orientation in High Temperature Boreholes

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Abstract

The Newcrest Lihir gold mine is located on Lihir Island in New Ireland Province, Papua New Guinea. The Ladolam deposit mined at the operation is located within a partially collapsed volcanic caldera. Ground temperatures as high as 230°C have been measured in holes at the mine. These temperatures produce an active geothermal regime at the mine, resulting in the potential for steam or gas “kicks” while drilling. As a result, drilling boreholes at Lihir requires specialist methods to guard against blowout from geothermal steam or gas pressure. These includes the use of blowout protectors, drilling all holes wet with mud and installing sections of permanent borehole casing to secure the blowout protectors and prevent post-drilling blowout.

These conditions present a challenge to data quality and coverage, but also require close attention to the safety of the drill crew and acoustic televiwer (ATV) operator and the serviceability of the orientation tools. The elevated temperatures make collection of in-situ orientation data significantly more difficult due to the blowout potential when drilling installation holes and when running downhole surveys and potential damage/loss of conventional downhole survey equipment which is typically rated to about 70°C.

Recent geotechnical drilling for the new Kapit pit has employed a number of techniques to measure the orientation of discontinuities encountered in the boreholes, either from the recovered core or by direct downhole measurement of the borehole wall.

A number of challenges were encountered setting up and conducting the ATV surveys, including the need to permanently case off the upper sections of the hole, poor ground conditions increasing the potential for borehole collapse, the need to quench the hole so that downhole temperatures did not damage the tool and to provide protection from gas “kicks” and the reheating of the hole while the quenching string was withdrawn and the tool was lowered into the hole prior to commencing the survey.

Protocols were established for selection of hole survey intervals, measuring quenching and heat up times and the safe launch and recovery of the ATV tool. Specialised equipment was designed and fabricated on site so that the safety of the ATV operator, drilling crew and tool was not compromised during the surveys. The protocols and equipment are described in this paper. The establishment and use of these protocols has allowed reasonable lengths of the boreholes to be surveyed safely, without risk to crew or damage to equipment in a hostile environment. Given the difficult conditions at the Lihir mine, this is a good result that has provided much useful data for developing the geotechnical model of the new pit.

1 Introduction

1.1 Background to Lihir deposit

The Newcrest Lihir gold mine is located on Lihir Island in New Ireland Province, Papua New Guinea. The island is located approximately 900km North-East of Port Moresby and is part of the Tabar-Lihir-Tanga-Feni Island Chain as illustrated in Figure 1. Rutter et al (2008) have suggested that the Lihir Group and other islands in the chain have developed with south to north convergence of the Solomon Sea Plate and the South Bismark Plate.
The Lihir gold mine hosts the Ladolam gold deposit. A major pre-historic eruption resulted in a sector collapse that left the north-east of the caldera open to the sea, forming Luise Harbour. Epithermal sulphide hosted gold mineralization is associated with residual geothermal activity that post-dated the caldera collapse.

The local geology consists of a wide variety of volcaniclastic rock types including breccia, tuff, lahar and lava flows (Rutter et al, 2008). Due to the chaotic nature of rock deposition or formation, the geology encountered can vary widely across the site. The classification of rock types for mining and geotechnical purposes is based on “ore type” which takes into account properties such as alteration, hardness, degree of brecciation and mineralogy. These ore types are strongly influenced by the weathering and geothermal regime.

Mining of the Ladolam deposit has been ongoing since 1997, commencing in the Minifie pit. Subsequently, the Lienetz pit, adjacent to the north of the Minifie pit, was opened. The Kapit pit, located north of the Lienetz pit, is next to be mined. The relative locations of the pits are shown in Figure 2.

Figure 1. Regional tectonics setting (from Rutter et al, 2008).
Ground temperatures and geothermal issues have increased as mining has progressed to the north. A considerable amount of effort has been directed towards gaining an understanding of the geothermal regime at the mine. A concept model of the geothermal regime has been developed based on the results of the drilling of geological, geotechnical, steam relief and geothermal exploration and production wells (Rodriguez et al, 2008). A section through this model is presented in Figure 3. The model shows a heat source located about 500m to 700m beneath the Kapit pit. Recent Pressure-Temperature measurements in steam relief wells in the Kapit area indicate downhole temperatures of up to 230°C. These temperatures correlate well with the model.
Due to operational constraints and the shortage of real estate for stockpiling, low grade ore was stockpiled in the Kapit area. This ore is to be processed or relocated to enable development of the Kapit pit. Geotechnical drilling carried out for the Kapit pit design has not only had to contend with high downhole temperatures and pressures, but also the need to drill through up to 80m thickness of stockpiled low grade ore and the poor quality ground immediately beneath it. This has made recovery of high quality geotechnical data difficult, particularly the ability to recover oriented core.

This paper looks at some of the issues encountered in recovering oriented core at the Lihir gold mine and some of the procedures developed for carrying out downhole ATV surveys in boreholes that have been completed either well before or just prior to survey. Comments on the focus on safety management of the activity and on the quality and length of borehole surveyed are also provided.

1.2 Previous geotechnical drilling

1.2.1 General

Drilling services are provided by a local landowner company. Due to the high ground temperatures and potential for gas “kicks” (a surge in pressure occurring when steam or gas under high pressure enters the borehole), drilling is carried out through a blowout protector (BOP). Once the upper section of the hole is cored, the drill string is pulled out and the hole reamed. Casing is run into the hole and cemented (grouted) into place. The BOP is then fitted and pressure tested.

Some of the issues encountered with drilling geotechnical drilling campaigns have included difficult and limited access to drill sites (requiring significant earthworks), very heavy and frequent rainfall (3,500 to 4,500mm/year) and land access issues.

1.2.2 Indirect core orientation

In early drilling campaigns, indirect methods have been used to orient the recovered core. An orientation spear was used initially with limited success due to the often broken condition of the end of the core run in the weak rocks. The Ezymark® system was introduced for the drilling campaigns in the Lienetz pit. Greater success was achieved until higher downhole ground temperatures encountered when drilling at the north end of the pit caused the Perspex window to fog/crack.

1.2.3 Direct core orientation

An optical televiewer (OTV) was also used with success in the Lienetz pit until ground temperatures at the northern end of the pit caused the polycarbonate viewing window to fog. The OTV did not measure and display temperature in real time. A thermal strip placed in the OTV measured downhole temperatures of about 70°C. In addition, clay smear that often occurred when drilling in the argillic rock needed to be washed down. The time taken for the wash down allowed the hole to heat up and limited the downhole survey length.

2 Current geotechnical drilling

2.1 Kapit pit drilling

The geotechnical drilling investigation for the Kapit pit commenced in late 2008. The Kapit area is north of the Lienetz pit, where heat issues with the Ezymark® and OTV were encountered. Significantly hotter ground temperatures were expected based on pressure-temperature surveys in steam relief wells in the area and the conceptual geothermal model shown in Figure 3. Much of this area is either covered by a low grade ore stockpile up to 80m thick, already used for roads and infrastructure or on the steep slopes of the caldera.

The stability of pit slopes is strongly influenced by unfavourably oriented structures. It was therefore important to identify discontinuities and measure their orientations in each borehole. However, this would require a tool
that was capable of operating in a high temperature environment. Following a detailed search and extensive enquiries, a suitable acoustic televiewer (ATV) was located and the process to mobilise it to site began.

2.2 Issues

The tool chosen for the downhole surveys was an ABI43 slimhole acoustic televiewer supplied by Advanced Logic Technology SA (ALT). This tool is rated for a maximum temperature of 125°C and 800bar pressure. The tool was to be hired to assess its performance and if satisfactory, purchase and operation by site was to be considered. A suitably qualified downhole logging contractor would need to be engaged to operate the tool.

For a number of reasons, mobilising the tool to site proved difficult and delays in commencing the ATV program were encountered. The issue of a work permit for the the contractor engaged to operate the hire ATV was also delayed due to rule changes that occurred during the permit application submission period.

The drilling program for the Kapit pit commenced in August 2008 and was completed in September 2009. As the tool and operator were not on site during drilling, the boreholes were fitted with well heads so a rig could re-establish over the boreholes to run the ATV survey. A drilling rig, rather than a light vehicle, was required to run the ATV into the hole due to the potential for blowouts and the need to quench the hole. Vibrating wire piezometers were also grouted into most of the boreholes following completion of the ATV surveys, while several others were lined with perforated steel casing and used as steam relief wells.

As a result, the boreholes were drilled in high temperature ground, cased off and left for periods of up to 18 months before the ATV survey was conducted. Some deterioration of the borehole walls occurred and most holes had to be re-drilled/cleaned/unblocked. Most of the upper sections of the boreholes could not be surveyed due to the casing. The ATV arrived on site in late November 2009 and the ATV surveys began the following month, approximately three months after drilling had been completed.

More recently, the ATV and operator have been on site while geotechnical infill drilling has been carried out. This has negated the requirement for the borehole to be revisited and allowed multiple ATV surveys to be run while drilling the hole.

3 Protocols for running ATV surveys

3.1 Re-mobilising over existing holes

The initial ATV surveys were done on the holes drilled some six to 18 months earlier. Once the ATV equipment and operator arrived on site and the rig was re-established on the hole, procedures were established for preparing and conducting the survey in the previously drilled holes.

3.2 Establish sections of borehole to be surveyed

Due to the length of time elapsed since the hole was initially completed, some of the rock units, especially the tuff, were potentially unstable or prone to overbreak while cleaning the hole. To ensure the safety of the ATV, these sections of the borehole (typically in the upper portions of the hole) were identified from the geotechnical logs and core splits photos and cased off.

3.3 Run in rods, clear blockages, quench and pull out

The drill string was run to the bottom of the borehole to clear any blockages and wash down the wall of the borehole. Water was then circulated for several hours to quench the hole before pulling the drill string out and running the ATV into the hole.

Initially, cool down/heat up tests were undertaken to determine the extent to which the downhole temperature could be reduced and how long it would take for the hole to re-heat to 125°C. Typical heat up time was about three to four hours. Eventually, the tests were stopped, as much of the heat up time was expended pulling rods
out of the hole. It was decided that following quenching for between three and six hours, the rods would be pulled and the ATV would be run into the hole. The temperature in the hole is measured by the ATV in real time as it is run in, so the survey would proceed until downhole temperatures reached 115°C. This provided a buffer while the survey was stopped and the ATV evacuated. An evacuation procedure was developed for recovering the ATV once the downhole temperatures reached the nominated cut off temperature.

### 3.4 Fit tee piece, circulate water

A tee piece was fitted to the casing to allow water to circulate in the hole. A rubber plug with a slot (‘guyverson device’) was fitted to the tee piece to allow the wireline to run into the hole and provide some containment of the water being circulated. The circulation of water increased the heat up time in some sections of the borehole.

### 3.5 Run in ATV, do survey

The ATV was run into the hole, either to the bottom of the hole or until the downhole temperature reached the threshold value. The exposed sections of borehole wall were surveyed as the tool was withdrawn.

Near the end of the ATV campaign, the ATV was run in without the tee piece. A small gas kick occurred which ejected the tool, sufficiently damaging the end of the ATV to cause survey work to be suspended. The kick not only highlighted the need to circulate water to keep the hole quenched, but that a means of containing kicks during the survey needed to be developed.

### 3.6 ATV concurrent with drilling

For the ensuing drilling campaigns, the ATV and operator were on site during drilling. The previously developed protocols remained effective. However costs were reduced as it was not necessary to re-establish the rig over the boreholes and the condition of the boreholes was better.

### 4 Development of a safe and effective ATV launch and recovery system

Following the gas kick that damaged the ATV, an isolation chamber was designed and fabricated on site to allow the safe launch, operation and recovery of the ATV tool.

The intention was to establish a means of ensuring that water was circulating and the hole was closed off while the tool was being set up over the hole. Once the tool was ready, the chamber could be opened and the ATV run into the hole with water still circulating. After the ATV survey was completed and the tool was back in the chamber, the hole would be closed off again and the tool and chamber removed. If a kick occurred during the survey, the tool would be retracted into the chamber and a drain valve opened to release any pressure built up.

A design was developed with input from the ATV operator, drilling supervisors and mine geotechnical personnel. The drilling contractor fabricated the equipment on site.

The components of the system were:

- A tee piece, screwed onto the casing thread to allow water to circulate through the hole.
- A ball valve, bolted to the tee piece so that the hole could be closed off. The ball valve could not fit directly to the casing, ensuring that the tee piece was always in place for the survey.
- An isolation chamber, bolted to the ball valve, in which the ATV was located prior to launch and after being retrieved.
- A guyverson device, plugged into the top of the isolation chamber, with a slot for the wireline.
- A drain tap, to allow release of any pressure built up in the isolation chamber.
A schematic of the ATV isolation chamber is shown in Figure 4. A photograph of the isolation chamber set up on the rig is shown in Figure 5.

Figure 4. Schematic arrangement of ATV isolation chamber.

Figure 5. Isolation chamber set up on the rig.
5 Results

The lengths of borehole that could be scanned using the high temperature rated ATV were mainly limited by downhole temperatures, particularly the deeper holes where the period of time required to pull the quenching string allowed the hole to heat up to temperatures above the 115°C cut off. This often meant that the deeper sections of the boreholes could not be surveyed.

Coverage of the near surface sections of the boreholes was also limited by the presence of the cemented casing, especially in the holes where re-establishment of the rig was required.

The need to case off poor ground that could collapse and prevent withdrawal of the tool and circulation of water, potentially “cooking” the ATV, also meant that coverage was limited in these sections of the boreholes.

A procedure to improve coverage, particularly in the near surface sections of the boreholes, needs to be developed. The next ATV campaign will be run concurrently with drilling and is likely to involve multiple runs in the borehole as drilling progresses.

Despite the age of the holes drilled during the initial Kapit drilling, the ATV operator commented that the boreholes appeared to have been drilled well and were in good condition.

The use of the ATV isolation equipment ensured water flow into the borehole and prevented any kicks from occurring during the ATV surveys where this equipment was used. As a result, the safety of the drilling crew during the survey process was not compromised and damage to the ATV equipment was prevented.

The main purpose of the ATV surveys is to provide data on structures down the borehole. Images from the ATV were used to identify and orient structures that were not identified due to core loss while drilling. The ATV data was also used to confirm the core orientation measured with an orientation spear. In general, there was reasonable correlation between the orientations measured by the ATV and the orientation spear.

6 Conclusions

The geothermal environment at the Lihir gold mine provides challenges for many mining activities. The challenges extend to the recovery of good quality geotechnical data due to the high temperatures and pressures encountered in the boreholes. The Geotechnical section at the Lihir operation has, together with the ATV operator and drilling contractor, developed procedures and equipment to safely retrieve quality discontinuity orientation data from the boreholes. The coverage of the boreholes is satisfactory, but further improvements to the survey procedure are planned to capture additional near surface discontinuity data.

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