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DEPRESSURIZATION AS A STRATEGY FOR MINING ORE BODIES WITHIN AN ACTIVE GEOTHERMAL SYSTEM

Romeo Rodriguez*, Zosimo Aunzo*, Jacqueline Kote* and Samuel Gumo*

*Lihir Gold Limited
P.O. Box 789, Port Moresby, Papua New Guinea
e-mail: Romeo.Rodriguez@lglgold.com

ABSTRACT

The Lihir Gold Mine in Papua New Guinea is a world-class open pit gold mine that contains an active geothermal system. Temperatures within the ore bodies are up to 200°C and this presents a major constraint to mining operations and creates the potential for geothermal hazards including hydrothermal eruptions. For mining to be feasible, it is necessary to depressurize and cool down the hot rocks of the pit to safe levels.

Drilling of steam relief wells ahead of mining is the primary method used to achieve depressurization. At the Lienetz pit where bench temperatures reach 130°C, the steam relief wells have been effective in lowering pressures and temperatures. This allowed conventional mining operations to proceed and also mitigates the risk of hydrothermal eruptions during mining.

Mining is advancing into the Kapit area where temperatures of up to 200°C and fluid pressures of up to 15 bars are expected. The strategy considered for this area is to depressurize the ore body to induce seawater encroachment to cool down the ore body. The challenge in this area is to achieve depressurization and cooling of the ore body without significantly affecting the deeper geothermal reservoir supplying steam to the mine's 56 MWe geothermal power plant.

INTRODUCTION

The Lihir gold mine, owned and operated by Lihir Gold Limited (LGL), is located on Lihir Island about 700 km northeast of the national capital, Port Moresby. Lihir Island forms part of the New Ireland Province of Papua New Guinea (Figure 1).

Figure 1. Location map of Lihir.

Lihir contains one of the world's largest gold deposits (Ladolam), with an estimated 40 million ounces in resource including 23.6 million ounces in reserves. Production mining commenced in late 1996. Open pit mining method is used with typical bench height of 12 m. Final pit design will be down to about 230 m below sea level. Most of the ore contains refractory sulfides requiring pressure oxidation before carbon-in-leach processing.

Lihir's Ladolam deposit is hosted within the remnants of a collapsed volcanic cone called the Luise Caldera. It contains 5 higher grade ore zones contained within a single large +1g/t deposit, 3 of which are scheduled to be mined till 2021. The higher grade portion of the Minifie ore zone has been mined out while current activity is focused on the Lienetz ore zone. The Kapit ore zone is presently overlain by a temporary low grade stockpile but is scheduled to start mining in 2012. Figure 2 shows the location and extent of the higher grade ore zones contained within the Ladolam Deposit.

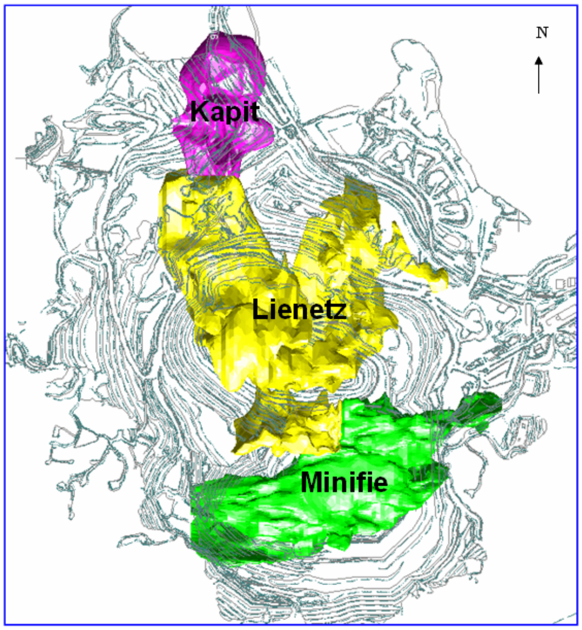

Figure 2. Location and extent of the higher grade ore zones contained within the Ladolam Deposit. Minifie has been mined out, Lienetz is currently being mined and Kapit is overlain by a temporary low grade stockpile.

The Luise Caldera also hosts an active geothermal system. The current geothermal model consists of two reservoirs:

1. A deep (> 800 m) reservoir with temperatures of up to 320°C.
2. A shallow reservoir, with temperatures up to 200°C, hosted within the permeable orebodies.

Since 2003, LGL has been harnessing the deep reservoir to supply steam for its geothermal power plants which currently has a combined capacity of 56 MWe. The deeper geothermal reservoir is an integral part of the total economic viability of the mine, providing 75% of the mine's electrical power requirements. It has earned LGL carbon credits under the Kyoto protocol, and has brought extra revenue and environmental awards.

In contrast, high temperatures and pressures in the shallow geothermal reservoir present a major constraint to mining due to geothermal hazards that include hydrothermal eruptions. To allow mining to proceed, the orebody must be depressurized and cooled down. This paper will discuss the major strategy developed by LGL to enable mining in this environment.

GEOLOGY

The Ladolam deposit is hosted within the collapsed Luise volcano. It has been postulated that the massive gold mineralization was formed after the collapse when sea water intrusion reacted with the gold-rich hydrothermal fluids.

The basic rock type composition comprises trachybasalt lava, volcanic breccia and tuff of Pleistocene age. The gold mineralized zones are hosted within extensively altered volcanic rocks, intrusives and breccias.

Due to intense alteration, an "ore type" classification has been developed based upon the various combination of alteration, hardness, degree of brecciation and or leaching of matrix material and the presence of late-stage anhydrite veining (Robinson, 2005).

The general ore types used in mining are:

- Argillic Zone
- Advanced Argillic (AA)
- Leached-Soaked Domain (LSD)
- Boiling Zone (BZ)
- Anhydrite Sealed (AHS)

Figure 3 shows a typical section through the mine showing the interrelationship between the various ore types.

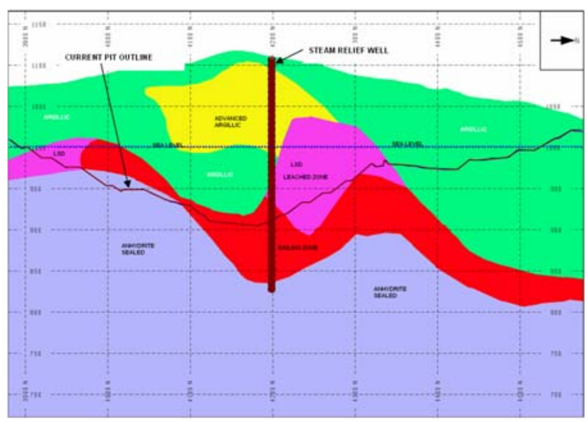

Figure 3. A typical section through the mine showing relationship between the various ore types. The boiling zone (BZ) and leached-soaked domain (LSD) are the permeable rocks that host the shallow geothermal reservoir.

Permeability characteristics play a large role in evaluating the hydrothermal eruption risks and the shallow reservoir behaviour. The argillic zone forms a relatively impermeable cap over the lower ore types. Advanced argillic are typical of areas near hot springs and thermal areas, LSD has permeable, leached structure and the boiling zone is the most permeable and holds most of the sulphide minerals containing the refractory gold.

GEOTHERMAL CONCEPTUAL MODEL

The current conceptual model is a deep geothermal reservoir with the upflow centered beneath the Kapit sector. The heat source is postulated to be cooling plutons and the reservoir is thought to be capped by tight anhydrite-sealed rocks.

A shallow, perched geothermal reservoir is hosted within the gold-bearing permeable ore bodies. The heat source appears to be conductive heating through the anhydrite sealed rocks. The hottest part of this shallow reservoir is below the Kapit area gradually cooling out away from the upflow zone. Thus, Minifie was quite cold with ground temperatures <90°C, Leinetz is hot with mining temperatures of up to 130°C and ground temperatures at the Kapit orebody are expected to be very hot (up to 200°C).

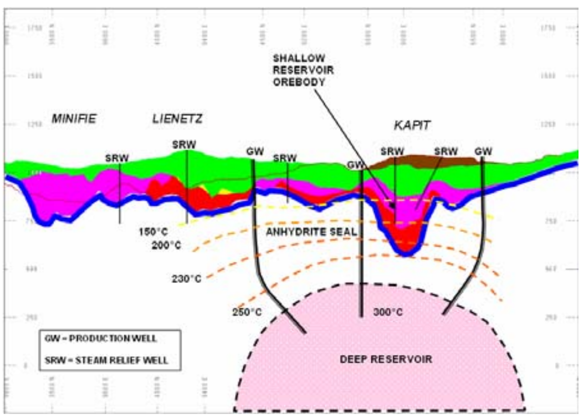

Figure 4. Section (not to scale) showing the conceptual model of the geothermal system inside Luise Caldera.

It is still unclear whether there is a vertical connection between the deep and shallow reservoirs.

GEOTHERMAL HAZARDS IN MINING

The shallow geothermal system hosted in the ore zones presents very challenging conditions for mining and gives rise to geothermal hazards. These are in the form of hot water sprays, geysers, boiling mud pools/volcanoes, high gas concentrations (particularly of H_2S) and geothermal outbursts. The latter is in the form of either small-scale pneumatic driven eruptions or large hydrothermal eruptions.

High temperatures and boiling or geysering water in the production blastholes requires strict procedures and controls to be followed to ensure explosives are not at risk of premature detonation. High temperature explosive like Orica's RDX is not recommended to be used above 150°C. High temperatures can also boil the products, and geysering holes eject the explosives before blasting. Explosive sleep times are also severely curtailed with high temperatures.

Villafuerte, et al., (2007) describes how LGL has developed some standard operating procedures for mining hot ground and potential geothermal outburst areas (PGOA). Critical equipments like shovels are fitted with bulletproof glass windows, thermal imaging cameras and full-face gas masks in the event of outbursts. Drilling rigs are required to have blow-out preventors. Strict personnel and vehicle exclusion rules are implemented during mining to prevent unnecessary exposure of personnel to geothermal hazards. Whenever feasible, all benches are drilled and blasted so that any potential high pressure area near the mining face is depressurized.

STEAM RELIEF WELLS

The most proactive outburst mitigation strategy for the mine is the drilling of steam relief wells (SRWs) well ahead of mining. This is to depressurize any potential high pressure traps and also to cool down the ground. A pressure of 2 bars and temperature of 120°C is considered the target for depressurization and cooling.

Information from SRWs, particularly pressure and temperature (PT) runs, are valuable in identifying and evaluating areas in the mine with a high risk of geothermal outburst.

A typical SRW is drilled to about 250–300 m deep and targets the Boiling Zone (BZ) and Leached-Soaked Domain (LSD). Figure 5 below shows a typical well profile.

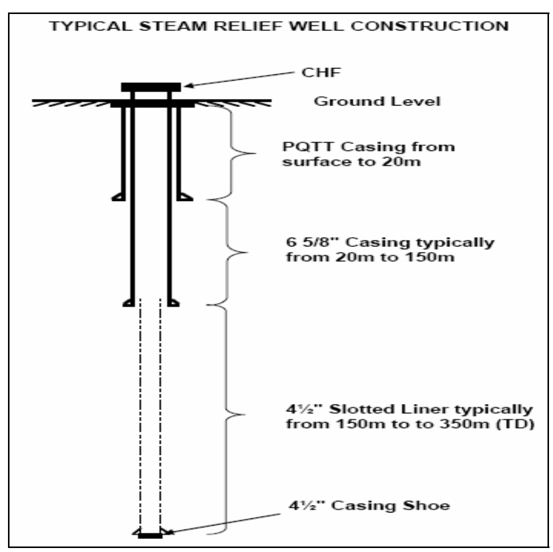

Figure 5. Typical steam relief well construction.

Effects of the SRWs are monitored mainly through shut-in pressure and temperature measurements. The SRWs are on continuous venting to the atmosphere. However, in instances where these wells need to be shut-in due to mining operations, pressure and temperature surveys are conducted. Figure 6 shows the location of currently drilled SRWs in the Lienetz and Kapit sectors.

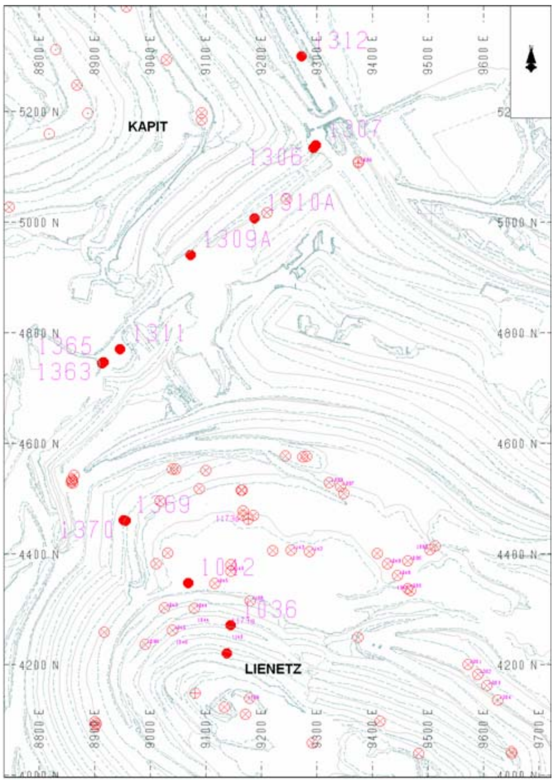

Figure 6. Locations of SR wells that were drilled around the Lienetz and Kapit sectors. The solid red circles are the wells with available PT data that were used in pressure drop analysis.

To date, there have been around 110 SRWs drilled since 2003. Half of these wells have been mined out, 35% are currently discharging with or without wellheads and the remaining 15% are on shut-in due to mining operations issues.

Mine operations prevent continuous monitoring and discharge of SRWs. Almost all of the SRWs in the Leinetz area have been mined out.

In rare instances, partially mined SRWs are cut and, if casing is sufficient, are reinstalled with wellheads to enable further monitoring. The majority of SRWs within the active mining area is left to vent to the atmosphere and are unable to be tested.

An analysis of pressure drops from SRWs that have monitoring data has been carried out. The results are plotted on Figure 7.

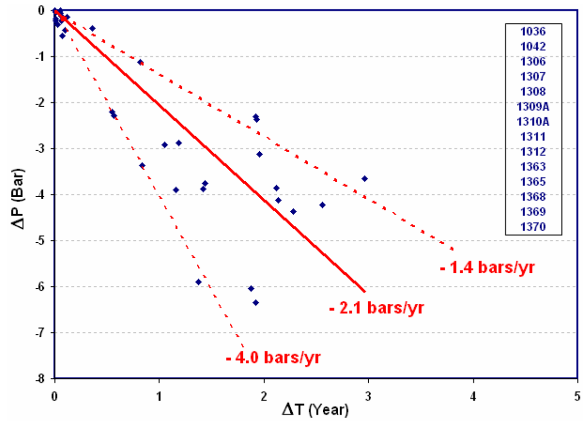

Figure 7. Observed pressure drops.

Pressure drops on the order of 1.4–4.0 bars per year are observed with an average pressure drop of 2.1 bars per year (Figure 7). Furthermore a contour plot of the pressure drop is shown in Figure 8. High pressure drops are seen in the Kapit drain area, even when no mining activities are taking place.

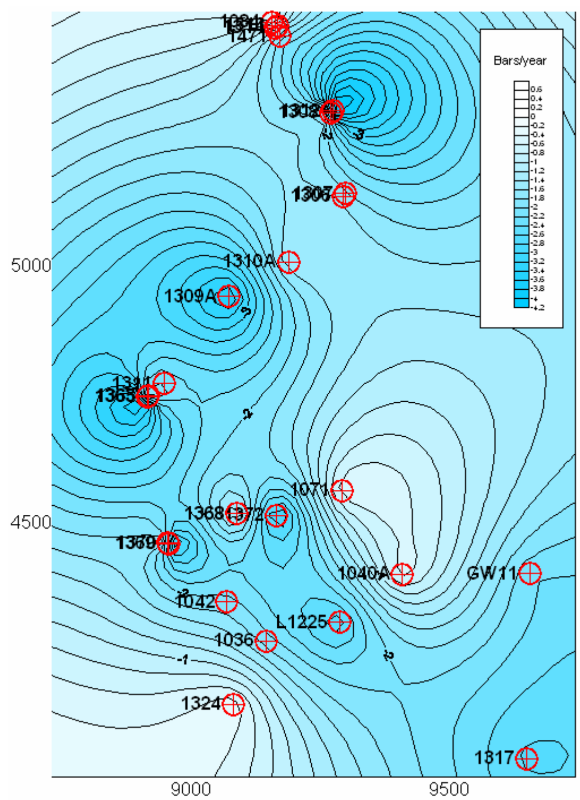

Figure 8. Contour of pressure drops on relief wells with monitoring data.

KAPIT DEPRESSURIZATION

Current data from initial steam relief wells suggest that the Kapit ore zone currently has temperatures of up to 200°C and pressures of up to 15 bars. With mining scheduled to commence in this sector in 2012, it is important that early depressurization and cooling is achieved.

The current plan is to drill additional SRWs to enhance further depressurization and cooling. These wells will be carefully planned and targeted to achieve maximum pressure drawdown.

The strategy which was developed from the numerical modeling studies of Industrial Research Limited (2003) is to promote the ingress of seawater in response to depressurization of the shallow geothermal reservoir in the Kapit area. This however relies on the existence of a permeable connection between the sea and the shallow reservoir. The presence of thermal features and gas bubbles in the sea, believed to be a manifestation of outflow conditions, tends to support a permeable pathway between the shallow reservoir and the sea.

There are potential problems in implementing this strategy. Seawater incursion into the shallow geothermal reservoir will bring changes to the reservoir chemistry. White, et al., (2003) cautions that heating of seawater causes the precipitation of anhydrite ($CaSO_4$) due to reverse solubility. This will tend to reduce the permeability of pathways between the shallow reservoir and the sea. Another problem can occur if there is direct vertical connection between the shallow reservoir and the deep reservoir in the Kapit area. The resulting quenching effect of the colder sea water on the deep reservoir may cause a diminution of the power plant's steam supply.

Another cooling strategy that is being considered is to carry out a dense pattern of SRW drilling incorporating reinjection of cold meteoric water pumped out of the current pits.

Chemical sampling and more information from new wells, backed up with further reservoir and hydrological modeling studies should further refine the conceptual model of the geothermal system which should help in formulating a suitable depressurization and cooling strategy.

CONCLUSION

The steam relief well strategy employed since 2003 by LGL has successfully depressurized the hot Lienetz orebody. To date LGL has seen pressure drops of between 1.4 and 4.0 bars per year, with an average pressure drop of 2.1 bars per yr.

A similar strategy is being employed in Kapit. However, the Kapit ore zone will require a greater degree of depressurization and cooling for mining to proceed in 2012. It is envisaged that drilling additional steam relief wells, properly targeted, can achieve the desired drawdown and cooling. Other strategies, including reinjection of cold water and cooling through induced seawater incursion, are also considered.

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