PLANNING FOR MITIGATION OF THE GEOTHERMAL SYSTEM TO ALLOW DEVELOPMENT OF THE LIHIR GOLD PROJECT, LIHIR ISLAND, PAPUA NEW GUINEA

John Forth[1], Anthony J. Menzies[2], Christopher W. Klein[2] and Wendell T. Howard[2]

[1]Lihir Management Company, Brisbane, Australia
[2]GeothermEx, Inc., Richmond, California, USA

Abstract

The Lihir Island orebody is located at an elevation just above sea level within the Quaternary-age Luise Caldera of Lihir Island, Papua New Guinea. The caldera is breached by the sea on its northeast side. Hot fluids rising from a still-active geothermal system are believed to have deposited gold in brecciated rocks of the caldera. The orebody is to be mined in a 2 x 1.5 km open pit that ultimately will reach a depth of about 220 m below sea level. Within the caldera, there is intense surface geothermal activity in the form of steaming ground, fumaroles, boiling springs and gas seeps. At the floor of the proposed mine, rock temperatures are as high as 170°C and immediately adjacent to the proposed western margin of the mine, temperatures reach 240°C at a depth of about 300 m.

To provide a design that will allow mining to proceed safely, GeothermEx, Inc. and Kennecott Corporation (a subsidiary of RTZ Corporation) performed extensive field investigations, conceptual modeling of the field and numerical simulation of the impact of excavation on the hydrological system. The dewatering and geothermal mitigation plan, which is based on the results of the numerical simulation studies, involves a combination of pumped wells, geothermal discharge wells, and pressure relief wells to dewater the pit, prevent hydrothermal eruptions, and prevent inflows of both hot geothermal fluids and seawater. Pumping will typically total about 1.25 m^3/s; *geothermal discharge will average about 200 kg/s; and together these are anticipated to draw the water table down to about 220 m below sea level during the planned 15-year mine life.*

1.0 INTRODUCTION

Lihir Gold, Ltd., with RTZ Corporation, Niugini Mining Ltd. and the Government of Papua New Guinea as major shareholders, plans to mine two contiguous gold orebodies (Leinetz and Minifie) located in the Luise Caldera, Lihir Island, Papua New Guinea (figure 1). Niugini Mining Ltd. first discovered the deposit, which is believed to be the largest undeveloped gold deposit in the world, in 1982 and detailed exploration was later conducted by Kennecott Corporation (an RTZ subsidiary) who also prepared the plan for mining the

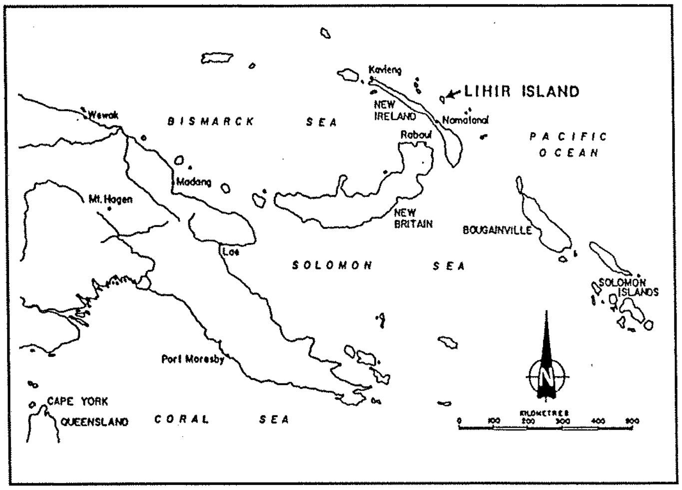

Figure 1: Location of Lihir Island, Papua New Guinea

deposit. The gold was deposited in the caldera breccias by rising hot fluids from a still active geothermal system to form the orebody which is to be mined in a 2 km x 1.5 km open pit that will ultimately reach a depth of about 220 m below sea level.

At the ground surface, fumaroles, hot springs and gas seeps define the present day 3 km^2 area of geothermal activity (figure 2); the northwestern half of the proposed mine lies within the area of surface geothermal activity. Characterization of the geothermal system in the sub-surface is based on data from over 300 drillholes and an extensive field investigation program conducted over a 6 year period.

The field investigation program included an extensive chemical sampling program of fumaroles, hot springs and discharging wells; analysis of 1,000 temperature logs from 300 bore-holes; 9 large-scale injection tests and 1 large scale pump-out test, including observation well monitoring; self flow discharge tests of 4 wells; measurement of tidal responses in 40 drillholes; packer permeability tests in 9 drillholes; pressure injection tests in 9 drillholes; falling head tests in 10 drillholes; air lift recovery tests in 7 drillholes, and an extensive program of water level monitoring.

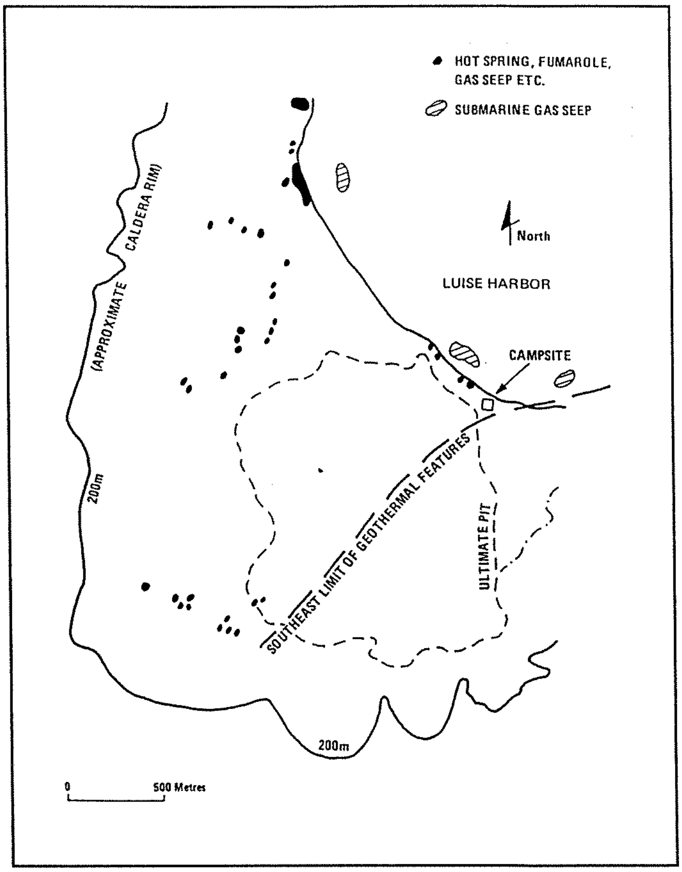

Figure 2: Surface geothermal features, Luise Caldera

Based on the extensive data base, the geothermal system appears to be fed by upflowing, hot fluid with temperatures at depth ranging from 250°C to 270°C and in some areas of the caldera, temperatures exceed 200°C at depths as shallow as 200 m. The geothermal fluid contains approximately 80,000 mg/l total dissolved solids, with major concentrations of sodium, potassium, chloride and sulfate, is pH neutral and contains 0.8% by weight gas (at approximately 20:1 carbon dioxide:hydrogen sulfide).

The uprising geothermal fluid, estimated to be approximately 50 kg/s under natural conditions, mixes with infiltrating rainwater and discharges through permeable breccias to the sea, with most of the discharge believed to occur where permeable zones outcrop on the sea bed approximately 200 m off-shore near the southeast limit of the geothermal features (figure 2). The location and permeability of the outflow zone is based on the results from the pump-out test and data from the monitoring of tidal responses. Additional discharge occurs at the surface thermal manifestations and at springs along the coast line.

The results from the injection and pump-out testing program show that the rocks within the defined pit area are generally very permeable to depths of about 250 m when compared with the surrounding unmineralized caldera wall rocks. This creates a permeable "bathtub" in the central part of Luise Caldera which is confined on three sides and at depth by relatively impermeable rocks. The "bathtub" is connected to the sea on the fourth side.

Because of the high permeabilities in the "bathtub", the water table through the ore zone is only slightly above sea level. Fluid pressures below the water table are generally hydrostatic, and no abnormally pressurized zones have been identified. Because of the lack of confining layers, no pressurized steam zones have been developed in the geothermal system, and the fluids present are predominantly in the liquid phase.

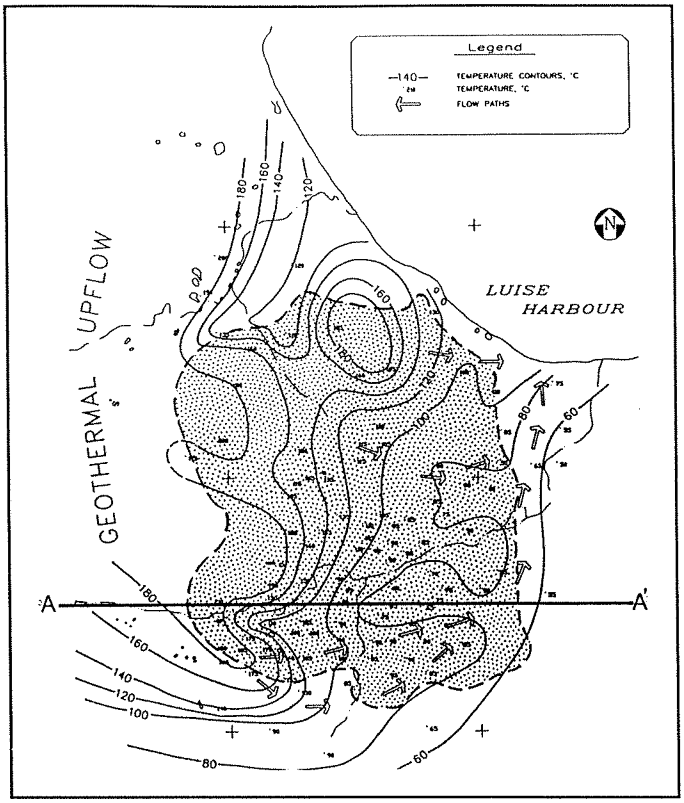

Figure 3: Temperature distribution at -150 m, msl

The data also clearly indicate that the geothermal and groundwater systems merge and mix and will hydraulically interact. Stress applied to any portion of the system, in the form of pressure change, will be transmitted throughout the system. No major hydraulic boundaries have been identified within the groundwater flow system, and no confining layers have been identified.

2.0 SUBSURFACE TEMPERATURES IN THE PROPOSED MINE AREA

The large body of subsurface temperature data provides the most comprehensive hydrological dataset collected. Figure 3 shows a temperature distribution map at -150 m, msl. Superimposed is the outline of the ultimate mine pit which will be excavated to its maximum depth elevation of approximately 220 m below sea level over a mining period of 15 years. Because the pit is cone shaped, the maximum rock temperatures that will be encountered will be 140°C although, as shown on figure 3, there will be higher temperature rock zones adjacent to, and below, the pit floor.

To the west of the proposed pit is an extensive area of geothermal upflow. Only one hot upflow zone has been identified within the proposed pit area, and this will not be mined until late in the mine life. All initial mining will be in the cooler area to the south and east where there is extensive cooling by meteoric water. This cooler zone to the south and east is also the principal outflow zone with most of the subsurface discharge occurring in the narrow zone bounded by the 60°C and 100°C temperature contours at the coast line.

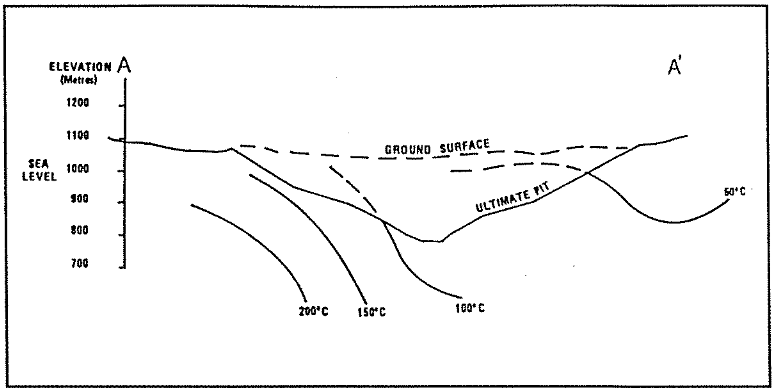

Figure 4: Temperature distribution on E-W cross section

Temperature contours on an E-W cross-section through the Lienetz and Minifie deposits are shown in figure 4; the location of the cross section is also shown in figure 3. In Minifie and the upper parts of Lienetz, temperatures are generally less than 100°C, while temperatures in the deeper parts of Lienetz range from 100°C to 200°C. The edge of the geothermal system occurs between the two ore bodies, approximately where the 150°C and 200°C contours dive off to depth.

It has been estimated that only about 25 percent of the total material to be mined at Lihir will be hotter than 100°C at the time of mining. The hottest rocks to be mined will be about 150°C, but these are deep in the Lienetz pit and are not scheduled to be mined until late in the mine life.

Within the geothermal upflow zones, boiling point for depth temperatures have been measured in about 20 drillholes. In all other drillholes, temperatures are below boiling point for depth conditions. That there are no temperatures in excess of boiling point for depth, indicates that in the upflow zones, there are no confining layers which might act as a cap for steam zones, or allow the development of high-pressure zones. The presence of boiling point conditions to the west of the proposed pit does indicate, however, that boiling and steam formation will occur as soon as depressurization is induced.

3.0 DEWATERING REQUIREMENTS AND IMPACTS

Water level data show that throughout the area to be mined, there is groundwater (geothermal and meteoric), in permeable strata, occurring to elevations just above sea level. The data also show that these groundwater systems are in good hydraulic continuity with Luise Harbour. Hydraulic testing has shown the presence of permeabilities sufficiently high that the strata must be dewatered if mining is to proceed and the selected pit design further requires that the pit walls must be depressurized to ensure their stability.

The dewatering of the strata in the pit will induce a zone of depressurization about the pit and impact the geothermal system. As the water table is lowered, there will be an increase in the upflow rate of hot geothermal liquid. It is not anticipated that these fluids will create new flow channels, or that these upflows will be at temperatures greater than now observed.

As pressures reduce, boiling will occur and steam will be formed. As a consequence, hot water and steam could flow toward the pit. If suitable geological conditions exist, pockets of pressurized steam could also form which will constitute a hazard if broached by mining.

It is proposed that the Lihir mine be dewatered by wells which will remove water from the strata to be mined, which will depressurize the walls, and which will intercept the seawater that would otherwise flow to the pit.

4.0 PROPOSED SUBSURFACE WATER MANAGEMENT

Based on detailed computer simulation studies (made for each individual year of mine life), a detailed groundwater (geothermal, stormwater and seawater inflow) management plan has been formulated. The elements of the plan are illustrated in figure 5. The principal operating element is a permanent wellfield of seawater interception wells to be located in Ladolam Valley, where ultimately an estimated 39 pump wells, averaging 250 m depth, are to be installed. These wells, each pumping at about 100 l/s, with an aggregate pumping of up to 1,300 l/s, will both dewater the pit area and intercept seawater being induced to flow toward the pit. Because of the very high permeabilities throughout the pit, it has been determined that by pumping from Ladolam Valley, the required pit dewatering through the life of mine can be accomplished from a single wellfield area sited outside of active working areas, an important consideration for a working mine.

The water pumped at the dewatering wellfield will comprise induced seawater inflow toward the pit, rainwater infiltrating to strata about and beneath the pit, and upflowing hot geothermal fluid. More than 80% of the water pumped will be seawater, and mixing at the area of the wellfield will ensure the cooling of the hot geothermal fluid to temperatures sufficiently low to allow for pump operation.

Geothermal wells (totalling 70 in number through the 15 year mine life) are to be installed around the western and northern margins of the pit, outside working areas, as shown in figure 5. The geothermal wells will be sited about the pit to intercept and extract hot geothermal fluid, to enable monitoring of the geothermal system and to allow for the safe venting of steam and hot water should any build up of pressure occur. In areas where permeabilities and temperatures permit, the wells will be set to discharge hot fluids and to reduce pressures, and thus enhance the dewatering effort. The geothermal wells are accordingly multifunction in purpose, and though not essential to the dewatering

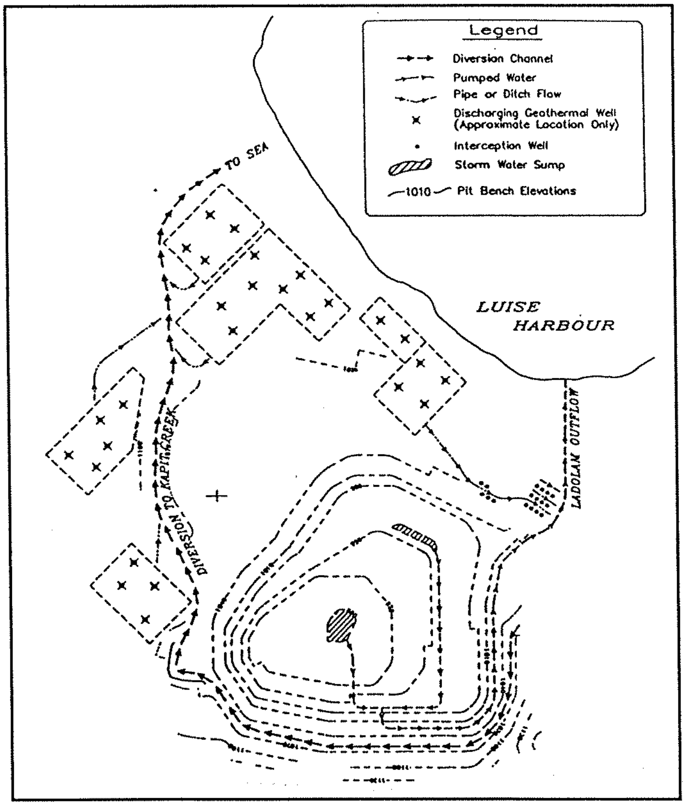

Figure 5: Conceptual water control management plan

effort in the early early years of mining, are deemed necessary from the earliest stages as a prudent safety measure for mine operations.

The proposed dewatering and geothermal control system offers the following important advantages:

- No geothermal or meteoric fluids (other than from minor perched aquifers) will enter the mine as seepage through the pit walls.
- The mining process itself will not impact upon the geothermal system.
- All geothermal installations will be operated outside the active pit.
- Dewatering can be achieved by operation of a permanent wellfield outside the active pit.

5.0 GEOTHERMAL IMPACTS

The impact of depressurization will spread well beyond the pit limits and will extend into known geothermal upflow areas. As boiling point for depth conditions are known to exist, depressurization will induce boiling and steam formation within the strata surrounding the mine. Extensive computer simulation studies have been directed toward evaluating the consequences of these impacts, and toward ensuring that appropriate mitigation measures are being planned where necessary.

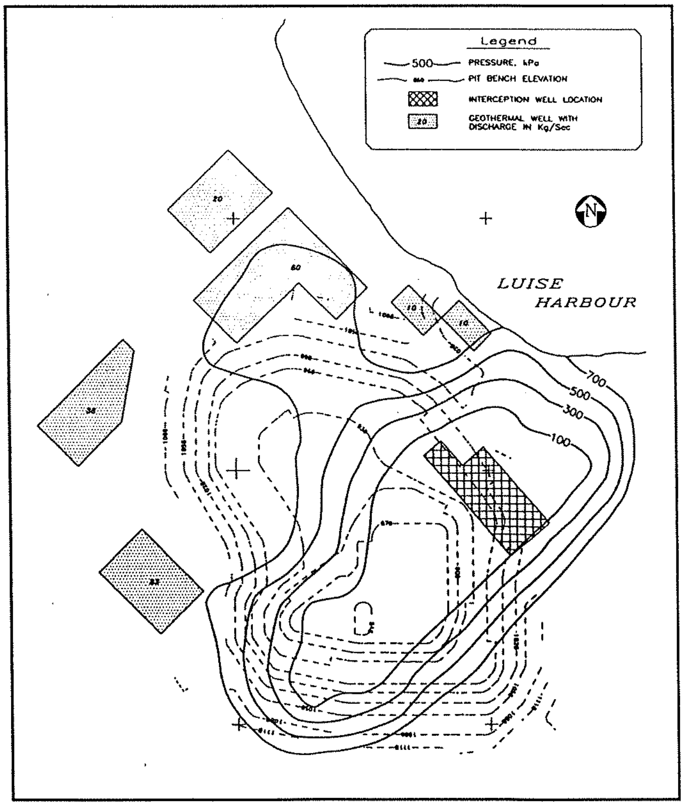

Figure 6: Calculated pressures (-150 m, msl) at Year 10

Figures 6 and 7 show the impact on the geothermal system at the tenth year of mining and the locations of the pumped dewatering wells and geothermal wells. By this stage the mine is at its maximum areal extent and in some portions approaching a maximum depth. The simulations were done on a year-by-year basis to allow for the rapidly excavated mine. It was found that from Year 10 to the end of mining at Year 15, geothermal effects do not differ significantly from those shown in figures 6 and 7.

Pressures within the geothermal system at Year 10 (figure 6) at -150 m, msl, are low and in the main pit area correspond to a water level below the pit floor, except in the sump area. There are no indicated areas of excess pressure development which could drive hot fluids or steam toward the working pit.

The simulation results (figure 7) show that the depressurization will result in the formation of shallow steam zones around the west margin of the mine and also in the coastal region. In the coastal area, steam saturation will exceed 40 percent; by Year 15, at the end on mining, computed steam saturations exceeded 50 percent at three locations, but with no indication of positive pressure buildup. With relatively low steam saturations, and because of the lack of pressure buildup, it is not anticipated that there will be steam and hot water flows to the pit. Geothermal monitoring wells will be installed to confirm this expectation, but if high pressures were to develop, these same wells would serve as vents to counteract the pressure increase. Additionally, these wells could be used for cold water injection to quench steam generation if such a need were perceived.

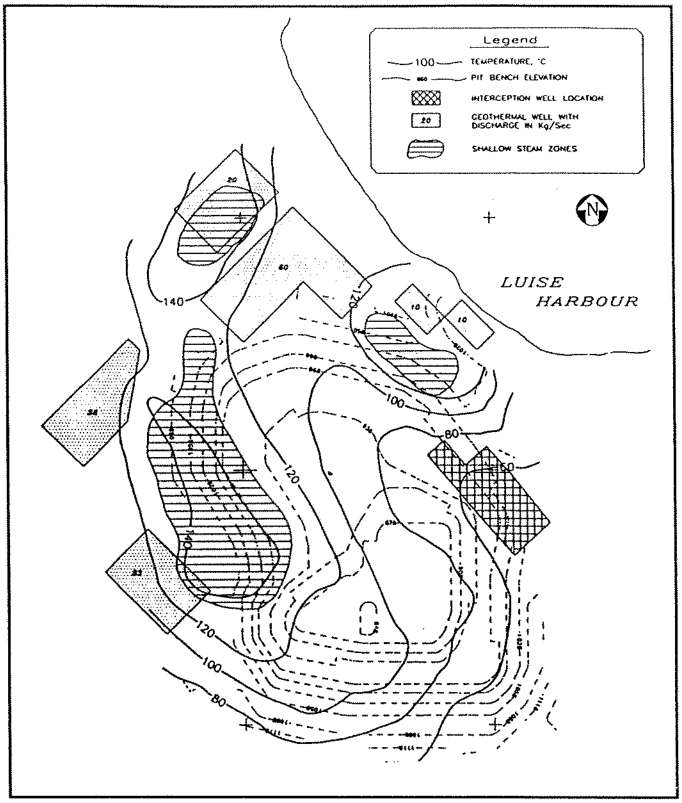

Figure 7: Areas of shallow steam formation and pit wall temperatures at Year 10

The estimated temperatures of rocks in the pit walls are also shown on figure 7. Maximum near pit rock temperatures at Year 10 are anticipated to be about 120°C in the southwest. These temperatures are computed within the rock mass and do not represent skin temperatures which will be close to ambient temperature. It should also be noted that within the simulations no allowance was made for the cooling that will result from the annual rainfall of almost 4 m (on an average 230 raindays) which will enhance the wall cooling.

Dewatering will also cause an increase in the rate of upflow of hot geothermal fluid although the increase will be small, relative to the total water pumping requirement. It is not anticipated that the dewatering will cause the ascending geothermal upflow to migrate into different flow channels, nor is it expected that the temperature of the geothermal system will increase. No significant temperature increases have been observed in producing geothermal systems elsewhere in the world, even in cases where the fluid extractions are at rates greatly in excess of those proposed for Lihir.

Some seeps and springs in the area west of the pit will dry up as a consequence of dewatering, and it is possible that geothermal activity could be instigated in some areas outside the pit perimeter that are presently geothermally inactive. Such activity is most likely to be seen as fumaroles, and low rate hot water seepages.

6.0 CONCLUSIONS

Computer simulations of a conceptual dewatering and geothermal management strategy indicate that it will be possible to construct and safely operate the proposed open cut pit in the Luise Caldera geothermal system at Lihir Island in Papua New Guinea.

The studies have shown that rock pre-cooling will not be necessary to allow safe mining, and that the required geothermal management, pit dewatering and seawater interception can all be accomplished with installations outside the actively working pit area, an important consideration for mine operation.

7.0 ACKNOWLEDGEMENTS

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