Modeling the Response of the Geothermal System at Lihir Island, Papua New Guinea to Mine Dewatering

Anthony J. Menzies[1] and John L. Forth[2]

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

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; the location of Lihir Island is shown in 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 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 geothermal system appears to be fed by upflowing, hot fluid with temperatures at depth ranging from 250°C to 270°C; 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 geothermal fluid mixes with infiltrating rainwater and discharges through permeable breccias to the sea; most of the discharge is 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 a pump-out test and data from monitoring of tidal responses in 40 wells. Additional discharge occurs at the surface thermal manifestations and at springs along the coast line.

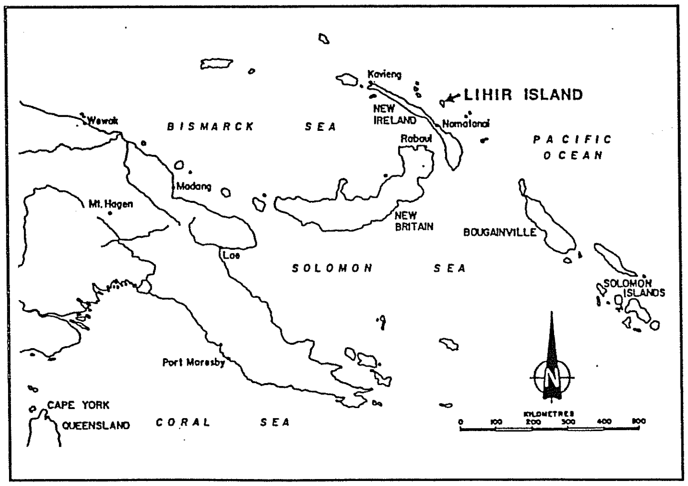

Figure 1: Location of Lihir Island

Results from a number of injection and pump-out tests 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.

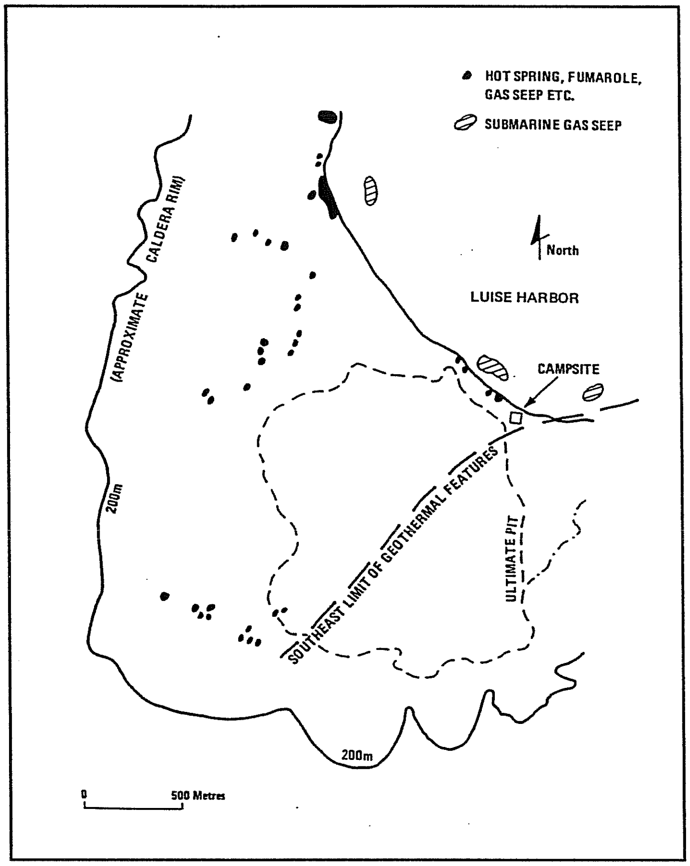

Figure 2: Surface geothermal features, Luise Caldera

The dewatering activities required to prevent sea water intrusion and to maintain "dry" conditions in the vicinity of the pit are expected to have a significant impact on the geothermal system. 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 that will constitute a hazard if broached by mining.

MODEL DESCRIPTION

To investigate the impact of dewatering on the geothermal system, a numerical model of the Luise Caldera was constructed using a version of the TOUGH simulation code. The model was first calibrated by matching the initial state of the geothermal system (subsurface temperature and pressure distribution); it was then used to forecast the changes in pressure, temperature and steam saturation that will occur on a year by year basis in response to dewatering activities.

The model of the Lihir geothermal system contains a total of 561 grid blocks, including blocks used to define the various boundary conditions. The grid blocks are distributed over six layers which cover the depth interval from the ground surface down to -800 m, msl; the layer boundaries and node levels are summarized in table 1, while the grid

Layer	Top Boundary m, msl	Bottom Boundary m, msl	Node Level m, msl
1	topo	-100	-50
2	-100	-200	-150
3	-200	-250	-225
4	-250	-300	-275
5	-300	-500	-400
6	-500	-800	-750

Table 1: Layer boundaries and node levels used in TOUGH model

layout on layer 1 is shown in figure 3. Figure 3 also shows the major geographical areas included in the model. The grid layout on each layer was primarily determined by the shape of the measured subsurface temperature distribution and the general shape of the mine, with more blocks being used in the upper layers compared with the lower layers.

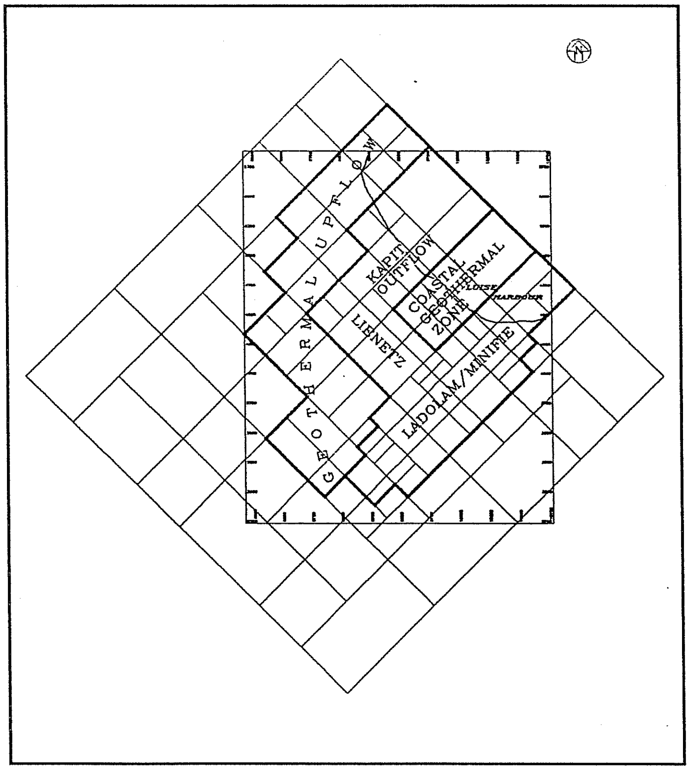

Figure 3: Model grid layout; top layer

Modeling of the geothermal system, including the geothermal upflow and interactions with the atmosphere, sea and infiltrating groundwater, required:

1. The use of the H_2O/CO_2 equation of state to allow the gas content (0.5 to 1.0 wt.-%) and thermodynamic conditions of the geothermal fluid to be more accurately modeled.
2. The use of constant pressure boundaries to model the interaction between the sea and the groundwater system.
3. The atmospheric boundary to be modeled as an open, constant pressure (100 kPa) boundary at constant temperature (30°C). The atmospheric boundary blocks are also

assumed to contain 100% CO_2 to approximate the properties of air. As dewatering proceeds, the CO_2 infilrates into the model, maintaining pressures at 100 kPa. In this way, the simulation model was used to approximate an unconfined system with a falling water table.

4. Constant rate point sources in selected blocks in the top layer to model infitration of meteoric water into the ore body.

5. The use of a constant pressure boundary at the base of the model to allow inflow of geothermal fluid at 240°C. Away from the upflow area, a conductive heat boundary with a temperature of 200°C was used.

6. Constant pressure boundaries on the sides of the top layer of the model to allow reasonable matches to be obtained to the measured pressure gradients within the system.

MODELING RESULTS

After specifying the model parameters and initial estimates of rock properties, the model was run and the results compared with the measured sub-surface distributions of temperature and pressure. After numerous runs, a reasonable match was obtained to the sub-surface temperature distribution and pressure gradients. The final rock types used in the model varied in permeability from 10^{-16} to $5x10^{-12}$ m^2; the lower permeabilities were mainly used on the sides of the model away from the geothermal upflow zone while the high permeabilities were used in the connection to the sea. The matching of the measured data required the inflows and outflows summarized in table 2.

After matching of the sub-surface data was successfully completed, the model was used to help develop the detailed groundwater (geothermal, stormwater and seawater inflow) management required for safe pit operation; the major elements of the plan are illustrated in figure 4. 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

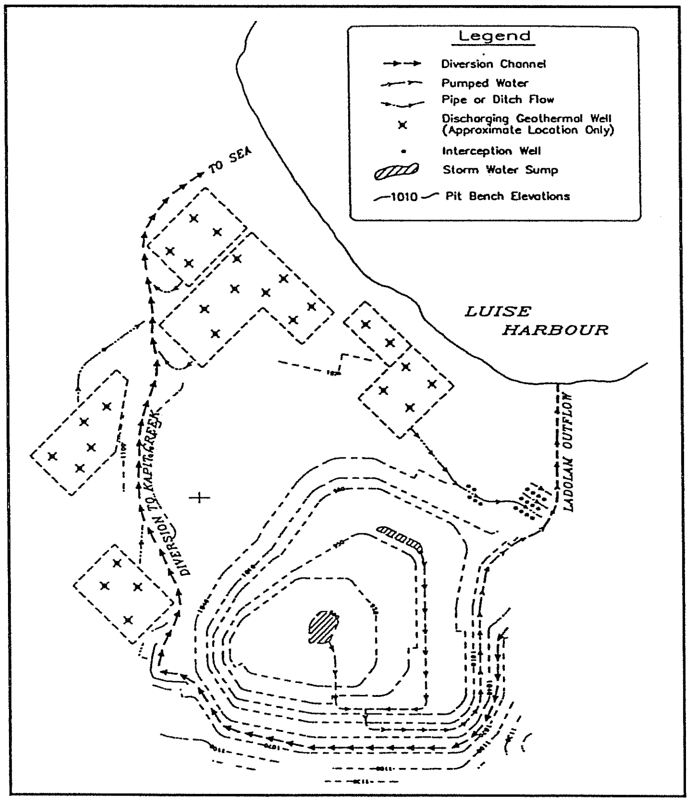

Figure 4: Conceptual water control management plan

Inflows to model		Outflows from model	
Geothermal upflow:	51.6 kg/s	Sea outflow:	98.3 kg/s
Infiltration:	37.9 kg/s	Atmospheric:	0.5 kg/s
Sides:	13.3 kg/s		
Total:	102.8 kg/s	Total:	98.8 kg/s

Table 2: Summary of mass balance required for initial state model

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.

Geothermal wells (totaling 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 4. 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.

The impact of depressurization will spread well beyond the pit limits and will induce boiling and steam formation within the strata surrounding the mine. Figures 5 and 6 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 maximum depth. As mentioned above, the simulations were conducted 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

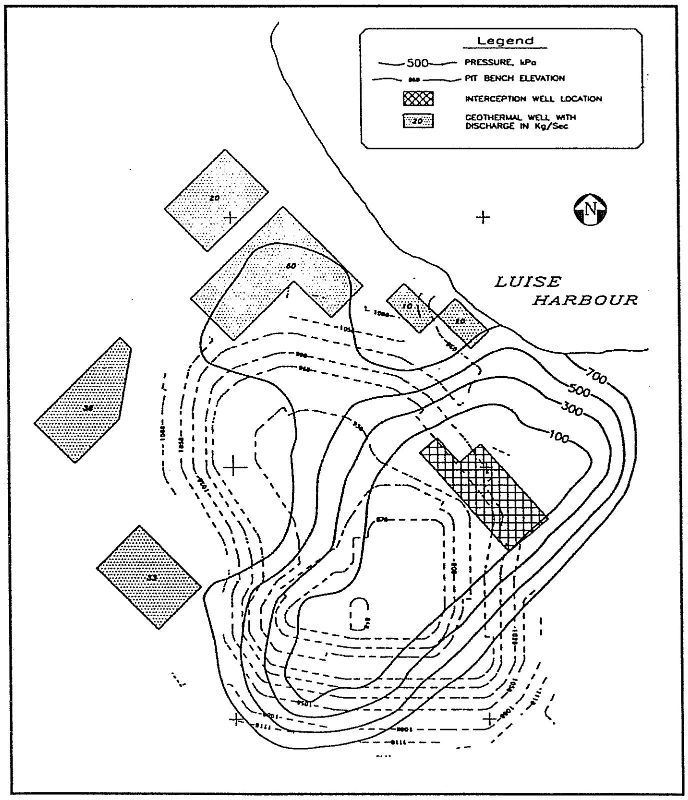

Figure 5: Calculated pressures (-150 m, msl); Year 10

significantly from those shown in figures 5 and 6.

Pressures within the geothermal system at Year 10 (figure 5) at -150 m, msl, 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. Depressurization will, however, 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%; by Year 15 (the end on mining), computed steam saturations exceed 50% in some areas. The changes in subsurface conditions, particularly the formation of steam, will be closely monitored during mine development using observation wells. 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.

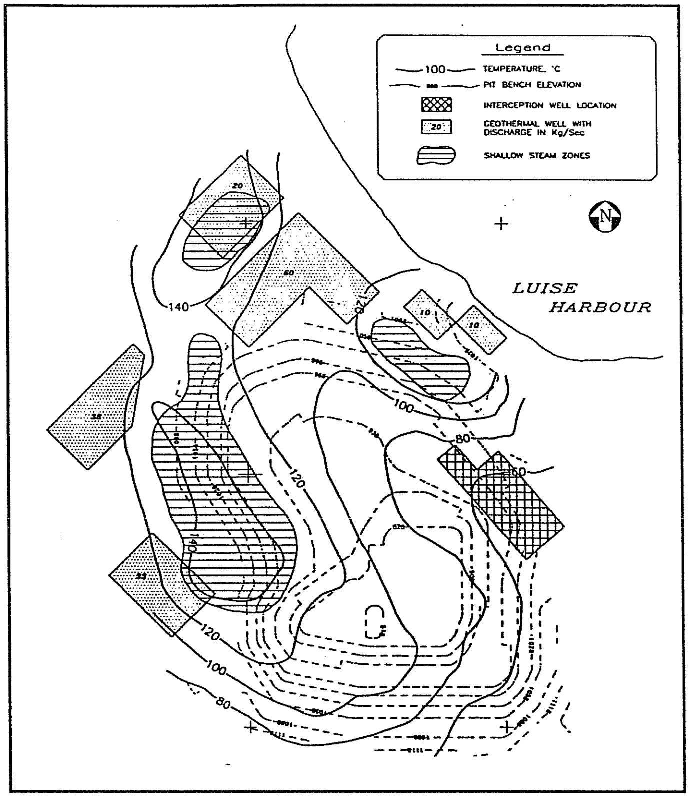

Figure 6: Areas of shallow steam formation and pit wall temperatures at Year 10

The estimated temperatures of rocks in the pit walls are shown on figure 6. 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 probably also result in 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.

Some seeps and springs in the area west of the pit will probably 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.

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.

ACKNOWLEDGEMENTS

The permission to publish this paper given by the Lihir Management Company, the RTZ wholly owned subsidiary responsible for managing the Lihir Project, is gratefully acknowledged by the authors.