

Preliminary Evaluation Update of Reservoir Potential of Southern Leyte Geothermal Project, Philippines

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ABSTRACT

The Southern Leyte Geothermal Project is located south of the renowned Tongonan Geothermal Field, at the southern tip of the island of Leyte, Philippines. Initial feasibility study conducted by the Japan External Trade Organization (JETRO) in 2001 – 2002 had estimated an available capacity of 110 MWe. Since then, an additional delineation well had been drilled and tested and reinterpretation of the geophysical survey were undertaken, providing new information on subsurface geology and reservoir characteristic of the geothermal resource. The updated study supports the previous findings of the initial study where a commercial size resource potential is present in the Southern Leyte Geothermal Project. High temperature (>260 C), neutral, high-chloride fluid is believed to be upflowing from the uplifted basement formation possibly heated by presence of magma chambers and intrusives (dikes) related to the volcanic activities in the area. Additional well drilling to delineate further the field are to be undertaken in the coming months.

1. INTRODUCTION

The Philippine Department of Energy's (DOE) National Energy Plan for 2004-2013 included an additional 600 MWe contribution from geothermal energy, of which roughly 410 MWe is expected to be tapped within the Visayas, and of which the Southern Leyte Geothermal Project (SLGP) will be a contributor. Initial feasibility study conducted by the Japan External Trade Organization (JETRO) in 2001-2002 of the Southern Leyte Geothermal Project (Mt. Cabalian geothermal resource) has estimated an available capacity of 110 MWe (JETRO, 2002). This report was based on drilling and well test data from the first well in the area, SL-1D, and the geoscientific data available at that time. These included the reinterpretation of geophysical surveys, particularly the magneto-telluric surveys where new data from additional MT stations were obtained (Rigor, et al., 2001). At that time also, SL-1D was not discharged due to the poor permeability of the well.

The current study provides an update on the recent development at SLGP and a re-evaluation of the resource potential with the additional information gathered from the newly drilled well SL-2D, and the reinterpretation of the geophysical survey of the resource.

2. DRILLING UPDATE

With the updated interpretation of the geoscientific model of the Cabalian reservoir (Rigor, et al., 2001 and Layugan et.al, 2004), two additional wells were proposed to be drilled in 2003 to supplement the well information provided by SL-1D. However, only SL-2D was drilled in the first half of 2003, with the drilling of the third well (SL-3D) deferred pending the availability of the rig that was moved

to the Tongonan geothermal field (Leyte Geothermal Production Field or LGPF) for production drilling.

SL-2D was drilled at Pad C situated at the northwest flank of Mt. Cabalian peak (Figure 1). The well was completed to 2493.7m measured depth (MD) (2362.3m vertical depth or VD) with a throw of 624.3m and azimuth of 354.5° (N 05.46° W) towards the western flank of Mt. Cantoyocdoc. Production casing shoe was set at 1547.7mMD with the slotted liner landed at the bottom of the well.

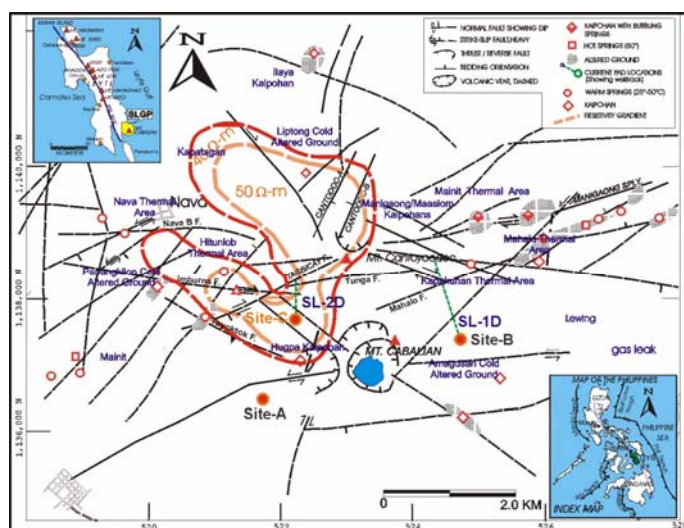


Figure 1: Location map of SL-2D showing initial geophysical boundary evaluated by Rigor, et. al. (2001)

Mineralogy encountered in SL-2D suggests higher temperatures than SL-1D. Estimated temperatures at the bottom of SL-2D range from 270 to 280 deg C, which was inferred to be masked by downflowing cooler fluids from the top zone. SL-1D mineralogy and actual/measured bottom temperature both show maximum temperature of only 240 deg C.

3. GEOLOGY UPDATE

Similar formations drilled through SL-1D were encountered in SL-2D, namely: Quaternary Volcanics (surface to 1085mVD) and the Tertiary Clastics (1085 to 2362mVD) (Zaide-Delfin, et al., 2003). In addition, hornblende dacite and microdiorite dikes intruded the Tertiary Clastics in SL-2D.

All four structural targets below the production casing shoe (based on the well design) were intersected by SL-2D. Geologic, petrologic and drilling data indicate good permeability for the intercepts of Imburna Splay, Tunga, Imburna and Tagbikay faults. An updated subsurface stratigraphy of the area with the two wells is shown in Figure 2.

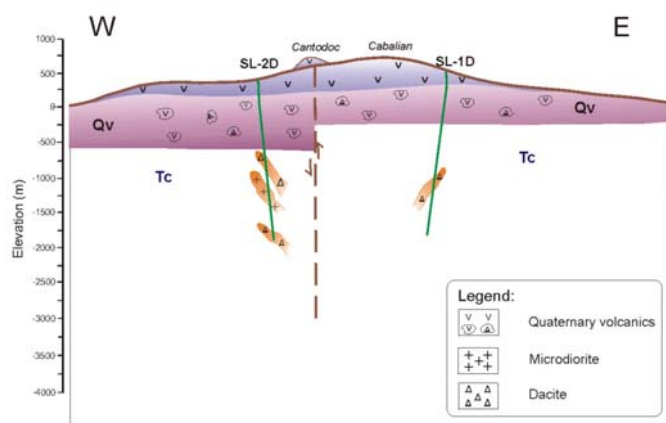


Figure 2: Stratigraphy of the Cabalian resource based on SL-1D and SL-2D.

4. GEOCHEMISTRY UPDATE

SL2D was discharged and tested at different wellhead pressure conditions from June 1 to July 31, 2003. The test ended when the well exhibited a steady drop in WHP with time until the flow finally collapsed.

Baseline chemistry discharge data from the well are generally stable at various wellhead pressures (from 0.45 to 0.11 MPaa) indicating the dominance of the shallow feed zone at 1800-2000mMD/1740-1920 mVD (i.e. the zone where Imburna fault was intersected) during the discharge. The chloride-enthalpy plot (Figure 3) indicate that SL2D's reservoir was boiled from 250 to 190°C, and this boiled SL2D brine, with Cl of 6,000 mg/kg, was then diluted (and eventually cooled) as it manifested to the surface, represented by Mainit and Mahalo springs.

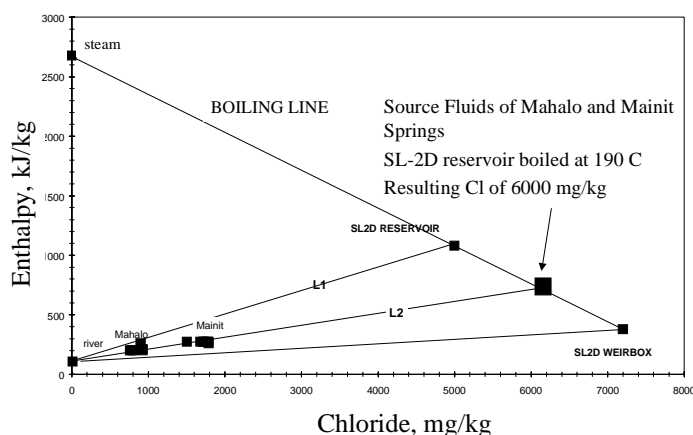


Figure 3: SL-2D chloride-enthalpy plot showing fluid source at about 250degC

The assumption of single source of springs and well fluids is based on Cl/B ratio, which ranges from 28 to 31, similar to the Cl/B ratio of SL2D (30). The springs' source temperature of 190°C is also well supported by silica mixing model. Sanchez (2003) estimated that the springs' most likely source temperatures ranged from 180 to 205°C assuming maximum steam loss. SL2D data, therefore, suggest a narrower spring source fluid temperature of 190°C, at a Cl concentration of 6,000 mg/kg.

5. GEOPHYSICAL UPDATE

Layugan, et al. (2005) provided a re-interpretation of the resource boundary for the Southern Leyte Geothermal System based on the additional MT data obtained in 2000-2001 (Rigor, et al., 2001). Layugan, et al (2005) inferred that the Cabalian system is most likely centered at the western flank of Mt. Cantoyocdoc as outlined by the uplifted resistive basement and represented by the mapped 40-100 ohm-m resistivity contour at -1500m elevation (Figure 4). From this uplifted resistive basement the outflows were drawn to coincide with the location of thermal manifestations. Outflow fluids to the east are channeled preferentially through the Mahalo Fault towards the Minit-Mahalo thermal area. On the other hand, geothermal fluid flows through the NW and EW trending faults (e.g. Nava, Imburna and Tayoktok Faults), which feeds the thermal springs to the west.



Figure 4: Iso-resistivity contour at -1500m RSL showing the geophysical boundary (from Layugan, 2005).

Minor outflows are also inferred towards the southeast and the north as indicated by similar trending faults and thermal manifestations within those areas.

6. WELL TEST UPDATE

Well SL-1D, despite having relatively high downhole temperatures, was found to be very tight and was no longer discharged. Computed transmissivity is only 0.16 d-m, and high positive wellhead pressures were monitored during the pumping tests.

SL-2D, on the other hand, underwent approximately 2-months discharge test but did not attain commercial output. This could be attributed to the well being severely damaged during drilling with about 14,700 bbls of mud lost in the open hole. The well is programmed to be acidized and retested, and expected to improve its output. Table 1 shows a summary of well information from SL-2D. Shut and flowing downhole temperature and pressure profile of the well are shown in Figure 5.

6.1 Predicted SL-2D Output

The likely output of SL-2D is estimated based on the initial discharge characteristics and assuming the formation damage will be removed after acidizing. This means that the low productivity index of 2.3 kg/s-MPa will improve and attain an equivalent value approaching the injectivity index of about 9 kg/s-MPa. Evaluation of productivity indices and injectivity indices of PNOC-EDC wells, indicate approximately a one-to-one correlation.

Wellbore simulation runs indicate that at 2.3 kg/s-MPa, a likely pressure drawdown of about 6.5 MPa will occur to attain a commercial wellhead pressure of about 0.7 MPa. The massflow and enthalpy at this WHP are about 16 kg/s and 1100 kJ/kg, respectively. With acidizing, the massflow is expected to increase to about 59 kg/s. Assuming the same enthalpy range, the output of the well is estimated to reach about 4.5 MWe (at an assumed 0.7 MPaa separation pressure and 2.5 kg/s-MWe steam rate).

Higher output may be attained if the fluid enthalpy will be higher, i.e. two-phase discharge or contribution from the hotter brine (270-280 deg C) at depth dominates the flow.

Table 1: SL-2D well data and output information.

INJECTIVITY	10 l/s-MPa	vacuum WHP throughout test
TRANSMISSIVITY	2-2.4 d-m	Initial analysis
SKIN	-2 to -3	Mud damaged during drilling (about 14700 bbls)
TEMPERATURE	235 C at 1600mMD	7 days shut survey after discharge
BLOCKAGE	1573mMD (using 5.5" GoDevil) 1935mMD (3" GD) (7 days after disch)	Liner bottom = 2491.7mMD Casing shoe = 1591.7mMD Top of Liner = 1567.7mMD
BORE OUTPUT	WHP = 0.11 MPag MF = 16.5 kg/s E = 1529 kJ/kg	At fully open condition (as of 14 July 2003) Discharge died 31 July 2003
FUTURE WORKS		Redischarge and retest the well after acidizing

7. CONCEPTUAL MODEL

The inferred heat source is located within the geophysical boundary defined by the updated geophysical survey, where the heat source is attributed to the presence of possible magma chambers and shallow intrusives related to the volcanic activities of Mt. Cabalian and Mt. Cantayocdoc. High-chloride, high temperature (260 deg C or higher) fluids upflow from the uplifted resistive basement formation (represented by the 40-100 ohm-m resistivity contour at -1500m), and outflows towards the east and west through major geologic faults. Minor outflows to the southeast and north as evidenced by the presence of thermal manifestations in both areas, may be attributed to similar trending faults which could channel the fluid.

The mineral assemblages found in both SL-1D and SL-2D suggest occurrence of neutral-pH fluid in the reservoir. However, high non-condensable gas (mainly CO₂) may be expected in the reservoir with the presence of carbonate-rich rocks in the formation. Mineral deposition in the well may be expected with the high calcite silica index obtained from the discharge fluids of SL-2D.

RESERVE ESTIMATE

Stored heat calculations, based on preliminary geoscientific surveys and downhole information from the two drilled wells in the area, were conducted to determine the estimated reserve capacity of the Mt. Cabalian resource in the Southern Leyte Geothermal Project.

The following reservoir parameters were used to compute for the reserve estimates:

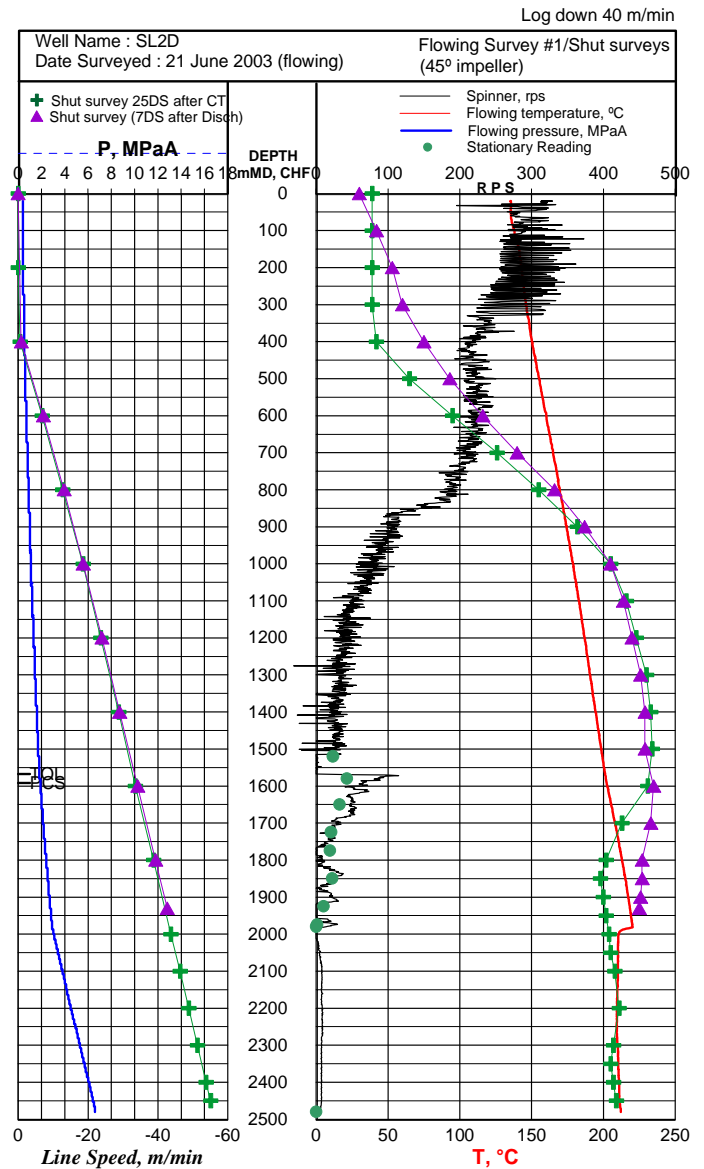


Figure 5: SL-2D downhole temperature and pressure profile.

8.1 Resource Area

Magneto-telluric surveys evaluated by Layugan, et al. (2005) showed a resource area of about 7.5-12 sq.km. representing the inner and outer boundaries, respectively (as shown in Figure 4). Well SL-1D is located outside the resource block, which would tend to confirm the low permeability encountered in the well. SL-2D is found within the resource boundary.

8.2 Resource Temperature

A cross sectional plot of the MT survey with the two drilled wells is shown in Figure 6 indicating also the estimated downhole temperatures in the wells based on analysis of petrological. A maximum temperature of about 270-280 deg C is estimated at the bottom of SL-2D while the highest temperature at SL-1D is about 240 deg C. Maximum measured downhole temperature at SL-1D closely matches the petrology data. On the other hand, downhole temperature data of SL-2D appear to be masked by cooler fluid downflowing from shallower depth (1600mMD). So far the highest temperature recorded in SL-2D is only 235 deg C at 1600mMD (near the production casing shoe).

The average reservoir temperature is estimated to be about 260 deg C, based on the temperature distribution from about –1000m MSL (where the 220 deg C temperature is expected) and the bottom temperatures expected in SL-2D and SL-1D. The 220 deg C limit is the temperature at which, based on PNOC-EDC experience, the fluid will flow to the surface, particularly for liquid reservoirs.

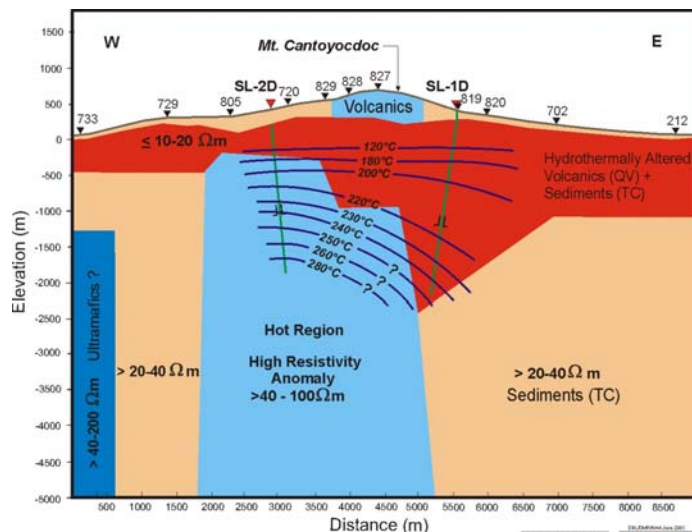


Figure 6: Cross section of the MT interpretation showing also the estimated downhole temperatures based on petrology and actual temperature data.

8.3 Resource Volume

The thickness of the reservoir is bounded by the 220 deg C isotherm as the upper bound of the reservoir (approximately at around –1000m MSL), and the –2500m MSL depth as the lower bound. The –2500mMSL is obtained by taking the average depth of SL-1D and SL-2D, and adding an additional 500m. to account for the additional heat that can be extracted from the rock by the fluid sweeping through the reservoir at depth. The computed thickness of the reservoir is therefore about 1500m.

8.4 Porosity and Recovery Factor

These parameters characterize the reservoir permeability, and how much fluid in-place within the reservoir can be extracted for power generation. For the stored heat calculations, we assumed a porosity of about 8%, which is typical for geothermal reservoirs developed by PNOC-EDC. The corresponding recovery factor, which is a function of porosity, is about 20% (Nathenson, 1975).

8.5 Conversion Efficiency

Bodvarsson (1974) and Nathenson (1975) evaluated the conversion efficiency of geothermal reservoirs from heat to electrical power as a function of temperature. At the estimated average reservoir temperature of 260 deg C, the conversion efficiency is estimated at 12%.

8.6 Plant Life and Load Factor

The expected plant life is about 25 years with an assumed load factor of about 92% equivalent to one-month PMS per year.

8.7 Stored Heat Calculations

Based on the above parameters and using straightforward calculations of the stored heat, the estimated reserve capacity that can be tapped for power generation is about 2132 MWe-years or about 85 MWe for 25 years.

A Monte Carlo analysis of the reserve estimate calculation was undertaken due to the uncertainties in the values assumed for each parameter in the stored heat calculations. Through this method, probability distributions were assigned to each parameter in the stored heat calculation that can affect the outcome of the calculations.

Monte Carlo simulation results indicate a mean capacity of 90 MWe for the Cabalian resource block.

9. SUMMARY AND CONCLUSION

The study supports the previous conclusion of the JETRO study in 2002 where a commercial size resource potential is present in the Southern Leyte Geothermal Project. Other findings in this study are:

- High-temperature (>260 deg C), neutral, high-chloride fluid is believed to be upflowing from within the resistive uplifted basement formation within the area enclosed by the 40-100 ohm-m block where the heat source is attributed to the possible presence of magma chambers and intrusives (dikes) related to the volcanic activities of Mt. Cabalian and Mt. Cantayocdoc. Outflows towards the east and west are dictated by fluid structures and supported by the presence of thermal manifestations (e.g. springs, kaipohans and altered grounds) in these areas. Minor outflows are also noted to the north and southeast that are also potential resource sites.
- The inferred reservoir block of about 7.5 to 12 sq.km. has a resource potential of about 85-90 MWe based on stored heat calculations and Monte Carlo simulation. The resource also has a 20% probability of attaining 130 MWe.
- Based on the expected output of SL-2D after acidizing, the likely average output of the wells in SLGP is about 4.5 MWe. Fluid chemistry of the well as well as the presence of calcite-rich rocks in the formation indicate possible occurrence of mineral deposition in the discharge.
- A more detailed monitoring of the SL-2D discharge should be conducted after the well is acidized. With the removal of the large volume of drilling mud deposited in the well, the higher output predicted in the well can be confirmed. In addition, the fluid temperatures at depth (particularly at the bottom where temperatures believe to range from 270 to 280 deg C based on petrology) will also be validated. The fluid chemistry of the well will be fully assessed for its potentials with regards to NCG and possible mineral deposition, particularly calcite.
- Additional well drilling should be targeted towards the west and further north to delineate and validate the resource boundary defined by the geophysical (MT) survey.
- A more detailed feasibility study can be conducted once the results of SL-2D acidizing and retest, and information from the additional exploration drilling are available.

REFERENCES

- Bodvarsson, G. Geothermal Resources Energetics. *Geothermics*, V.3., 1974
- Delfin, M.C.Z., Catane, J.P.L., Bien, O.C. and Rosell, J.B. Geology and Petrology of Well SL-2D Southern Leyte Geothermal Project. *PNOC-EDC Internal Report*. July 2003
- JETRO. The Feasibility Study on Geothermal Power Plant Project in Cabalian, Southern Leyte in Philippines. *Commissioned by the Ministry of Economy, Trade and Industry of Japan. Japan External Trade Organization*, March 2002.
- Layugan, D.B., Rigor, D.M., Apuada, N.A., Los Banos, C.F. and Olivar, R.E. Magnetotelluric (MT) Resistivity Surveys in Various Geothermal Systems in Central Philippines. *Proceedings, World Geothermal Congress*. Antalya, Turkey. 2005. In preparation.
- Nathenson, M. Physical Factors Determining the Fraction of Stored Heat Recoverable from Hydrothermal Convection Systems and Conduction Dominated Areas. *USGS Open File Report 38*. 1975
- PNOC-EDC. Geoscientific exploration and evaluation of the Mt. Cabalian Geothermal Prospect, Southern Leyte. *PNOC-EDC internal report*. 106 pp. 1989.
- Rigor, D.M., Catane, J.P.L. Layugan, D.B. Imaging the Southern Leyte Geothermal System Using MT Data. *PNOC-EDC Internal Report*. July 2001.
- Rosell, J.B. and Zaide-Delfin, M.C. Resource Potential of the Southern Leyte Geothermal Prospect, Philippines: A Geologic Evaluation. *Proceedings, World Geothermal Congress*. Antalya, Turkey. 2005. In preparation.
- Sanchez, D.R. Geochemistry of Medium Term Discharge of SL-2D of Southern Leyte Geothermal Project (June 1 to July 31, 2003). *PNOC-EDC Internal Report*. November 2003.